

# Satellite Image Automatic Mapper™ - SIAM™ -



Landsat 7 ET+ image of Pakistan, in false colors (RGB: 5-4-1). Path: 149, Row: 036, acquisition date: 2001-09-30, Pakistan

An operational (good-to-go, turn-key), fully automated, multi-sensor, multi-resolution, efficient and accurate methodology for the (preliminary) classification of radiometrically calibrated remotely sensed images.



Preliminary classification map.

**Andrea Baraldi**

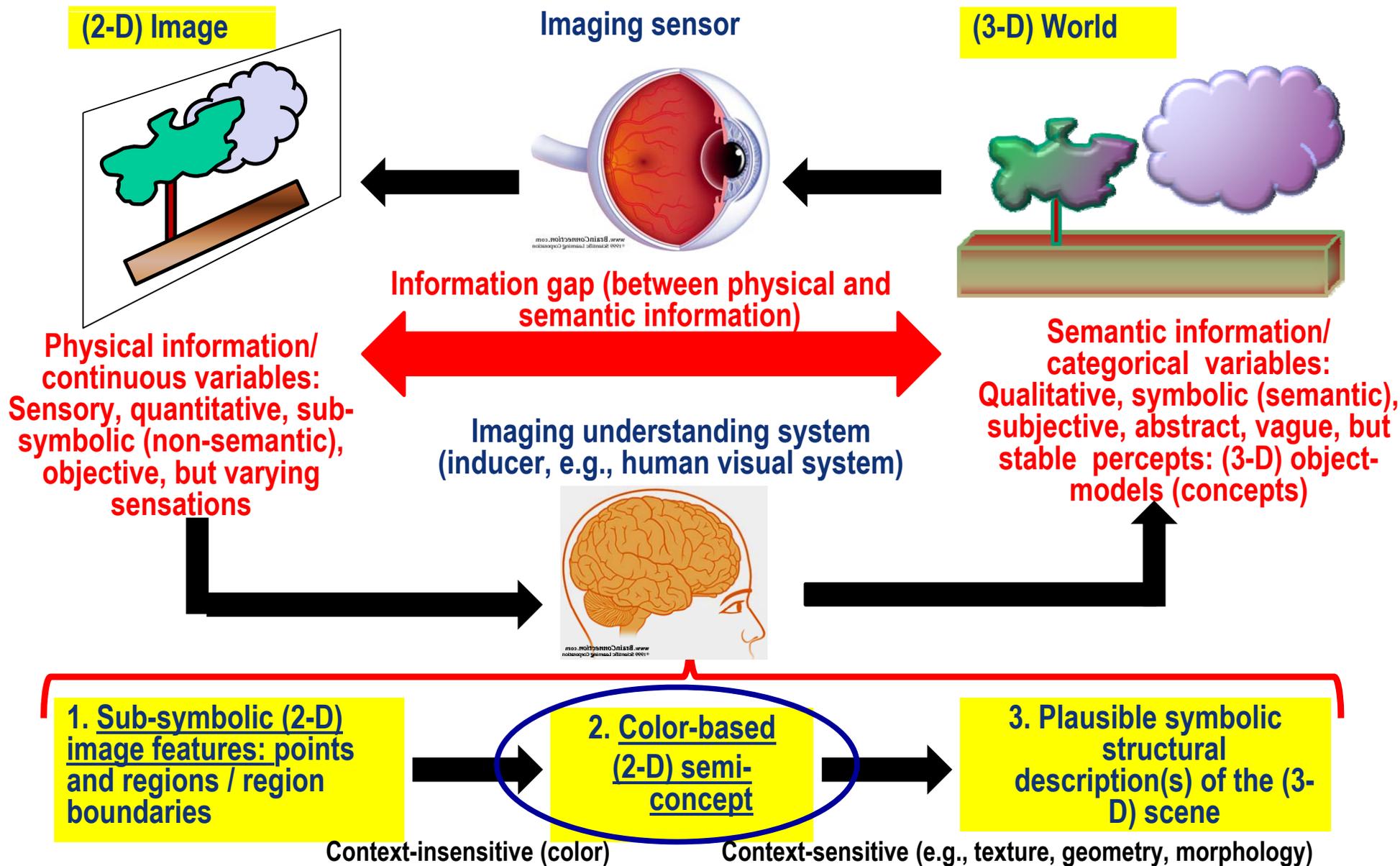
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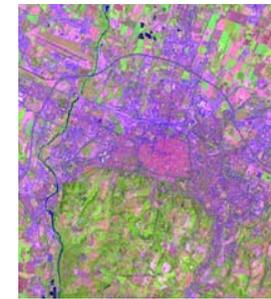
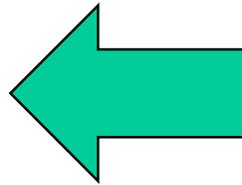
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# Inherently ill-posed image understanding problem (vision)

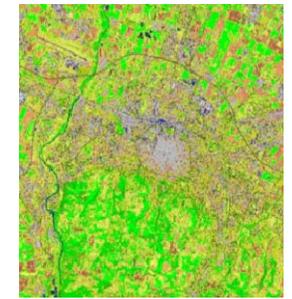


# Spaceborne EO data products taxonomy

1. Land cover composition (categorical variables).

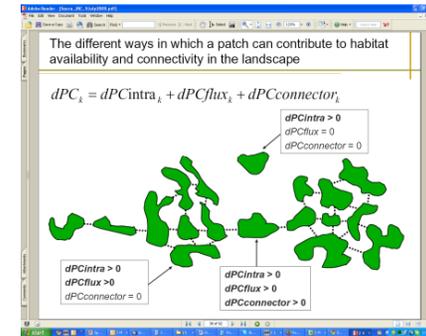


Satellite image



Land cover (LC) map

2. Landscape structure (e.g., fragmentation).

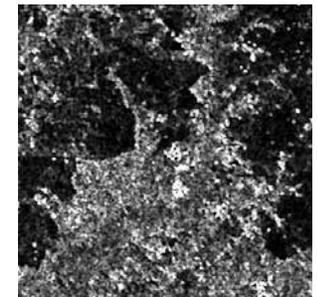


Patch compactness,  
Patch connectivity,  
Patch viscosity

3. Continuous variables estimation (e.g., leaf area index).



Satellite image



Greenness index

## Four levels of understanding of an information processing system (Marr, 1982)

1. **Computational theory (system architecture).** According to Marr at this level is the lynch-pin of success of an information processing system!!!  

2. **Knowledge/information representation** (e.g., crisp versus fuzzy reasoning).
3. **Algorithm.**
4. **Implementation.**

# Preliminary spectral rule-based image classification: Summary of operational properties

## Symbolic pixels in symbolic segments in symbolic strata

QuickBird-2 MS scene. False color image (R: band 3, G: band 4, B: band 1).



Step 1.



Preliminary classification map, in pseudo colors, generated from the calibrated image. It consists of labeled pixels/segments/strata.

**Traditional two-stage segment-based RS-IUS**

**Novel two-stage stratified RS-IUS**

Contour image extracted from the preliminary classification map.

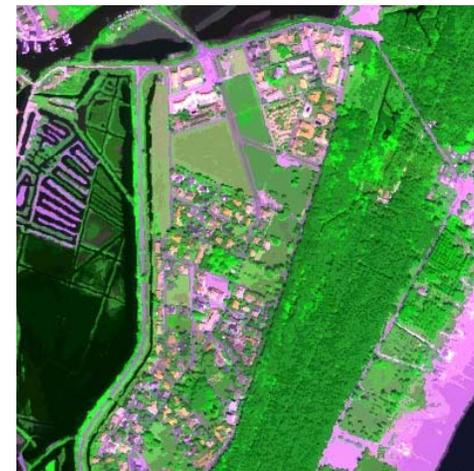
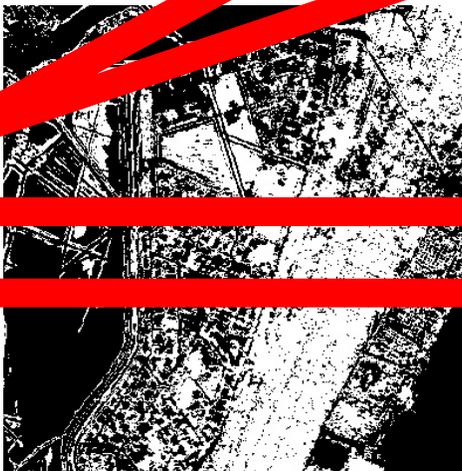
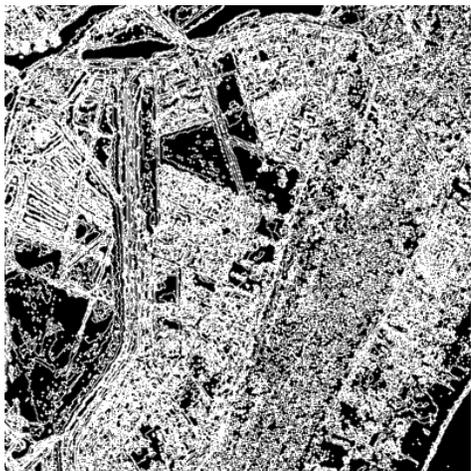
Step 1

Example of a color-based (e.g. vegetation) stratum extracted from the preliminary classification map.

Step 2.

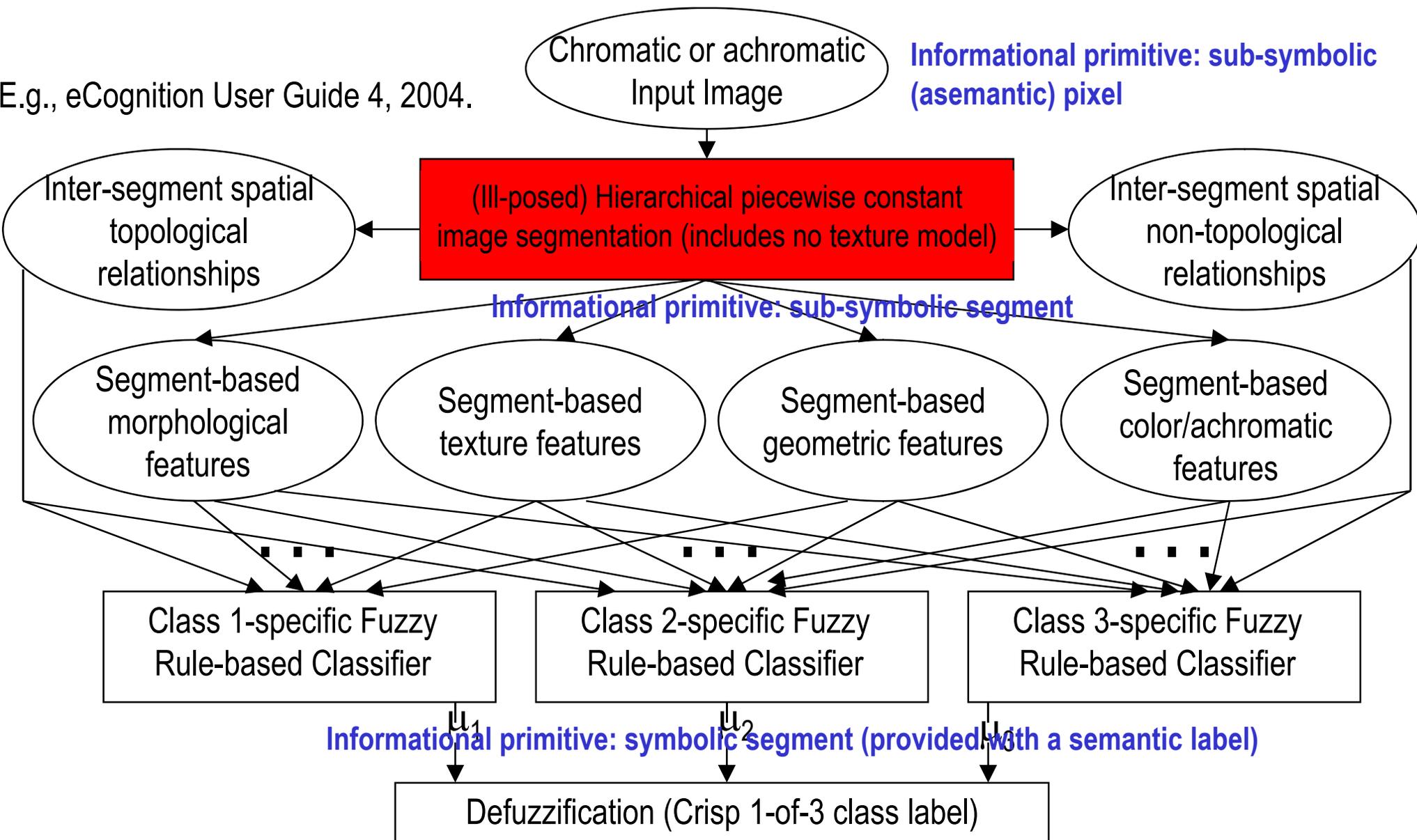
Segment-based piecewise constant image approximation (ENVI: region mean).

Step 2.

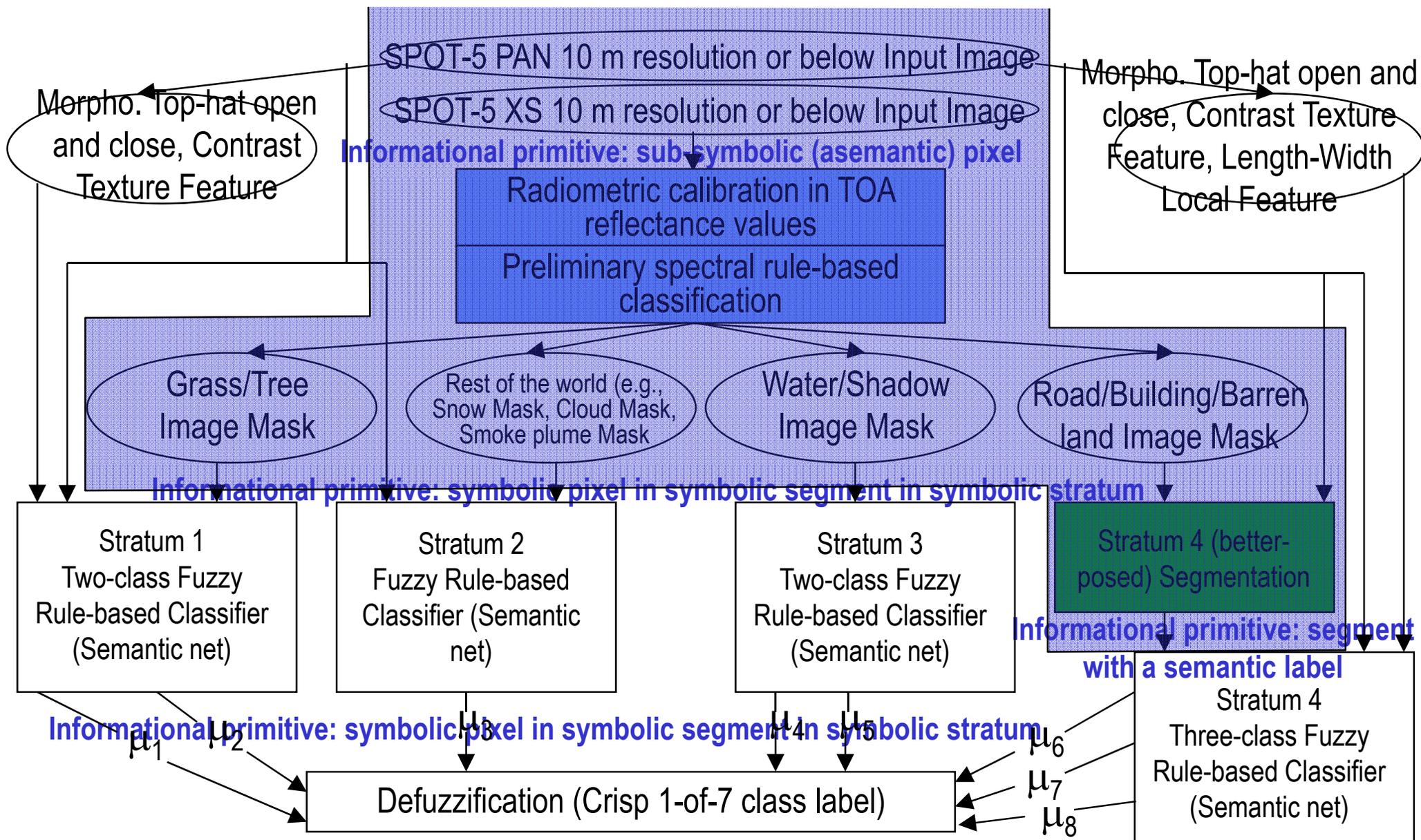


# Two-stage segment-based RS image understanding system architecture

E.g., eCognition User Guide 4, 2004.



# Two-stage stratified hierarchical RS-IUS architecture (Baraldi, 2006-2010)



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## Preliminary image classification: rationale in computer vision

Simple inferences between surface colors found in nature in the visible portion of the electromagnetic spectrum and semantic classes of 3-D objects in the world.

Color in nature	Semantic conjecture
Black	Soil with organic matter, oil.
Gray	Bare exposed rocks, Soil with clay and sand (with gray tones inversely related to soil moisture), Dirty snow.
White	Snow, Ice, Cloud.
Blue	Water.
Light blue	Sky.
Green	Vegetation, Water with green alga.
Brown	Soil with clay and silt, Water with suspended clay, Bricks, House tiles.
Pink	Special rocks (e.g., pink granite).
Red	Soil with iron oxide, Water with red alga, House tiles.

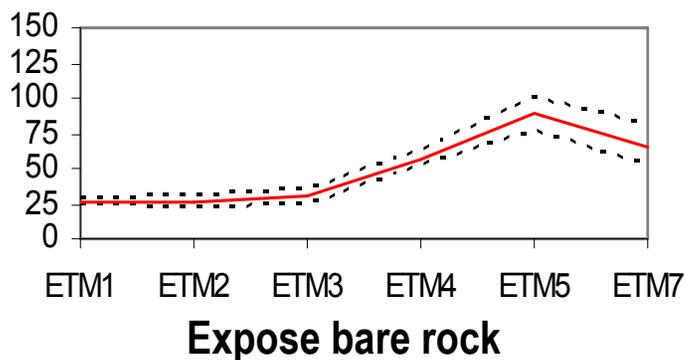
## Extension of the GEO-CEOS Quality Assurance Framework for Earth Observation (QA4EO) guidelines to automatic EO data processing

**RADIOMETRIC CALIBRATION not only ensures the harmonisation and interoperability of multi-source observational data according to the QA4EO guidelines, but it is A NECESSARY, ALTHOUGH NOT SUFFICIENT, CONDITION FOR AUTOMATING an EO data processing system.**

Commercial RS-IUSs	Radiometric calibration requirement
eCognition Server by Definiens AG	NO RAD. CAL. $\Rightarrow$ semi-automatic and site-specific. Inconsistent with the QA4EO.
PCI Geomatics GeomaticaX	NO RAD. CAL. $\Rightarrow$ semi-automatic and site-specific. Inconsistent with the QA4EO.
Pixel- and Segment-based versions of the Environment for Visualizing Images (ENVI) by ITT VIS	NO RAD. CAL. $\Rightarrow$ semi-automatic and site-specific. Inconsistent with the QA4EO.
ERDAS IMAGING Objective	NO RAD. CAL. $\Rightarrow$ semi-automatic and site-specific.
ERDAS ATCOR3	Surface reflectance, $\rho \Rightarrow$ inherently ill-posed atmospheric correction first stage. Consistent with QA4EO, but semi-automatic and site-specific.
Proposed two-stage stratified hierarchical RS-IUS architecture	Top-of-atmosphere (TOA) reflectance (TOARF) or surface reflectance $\rho$ values, with $TOARF \geq \rho \Rightarrow$ atmospheric correction is optional. Consistent with QA4EO. Fully automated (no user-defined parameter, no training sample).

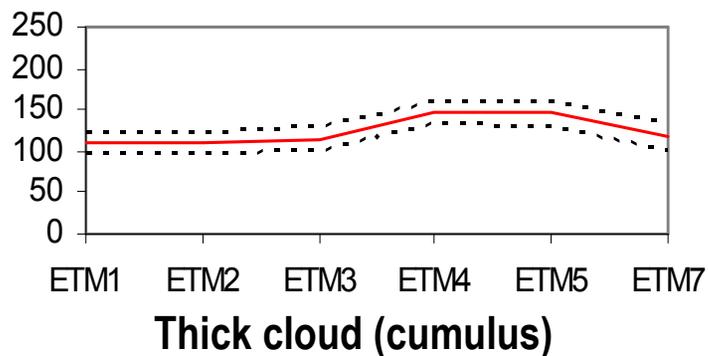
# Reference dictionary of spectral signatures in top-of-atmosphere (TOA) reflectance (not surface reflectance!) values

Pakistan, p149r036



Subset_Pakistan_p149r036_01	Min	Max	Mean	StDev
ETM1	23	29	25.68	1.61
ETM2	22	30	25.40	1.72
ETM3	25	35	30.18	2.27
ETM4	53	62	57.05	2.23
ETM5	76	99	88.07	3.07
ETM7	52	80	64.28	5.48
ETM62	131	133	132.30	0.77

Carpathian, p186r026

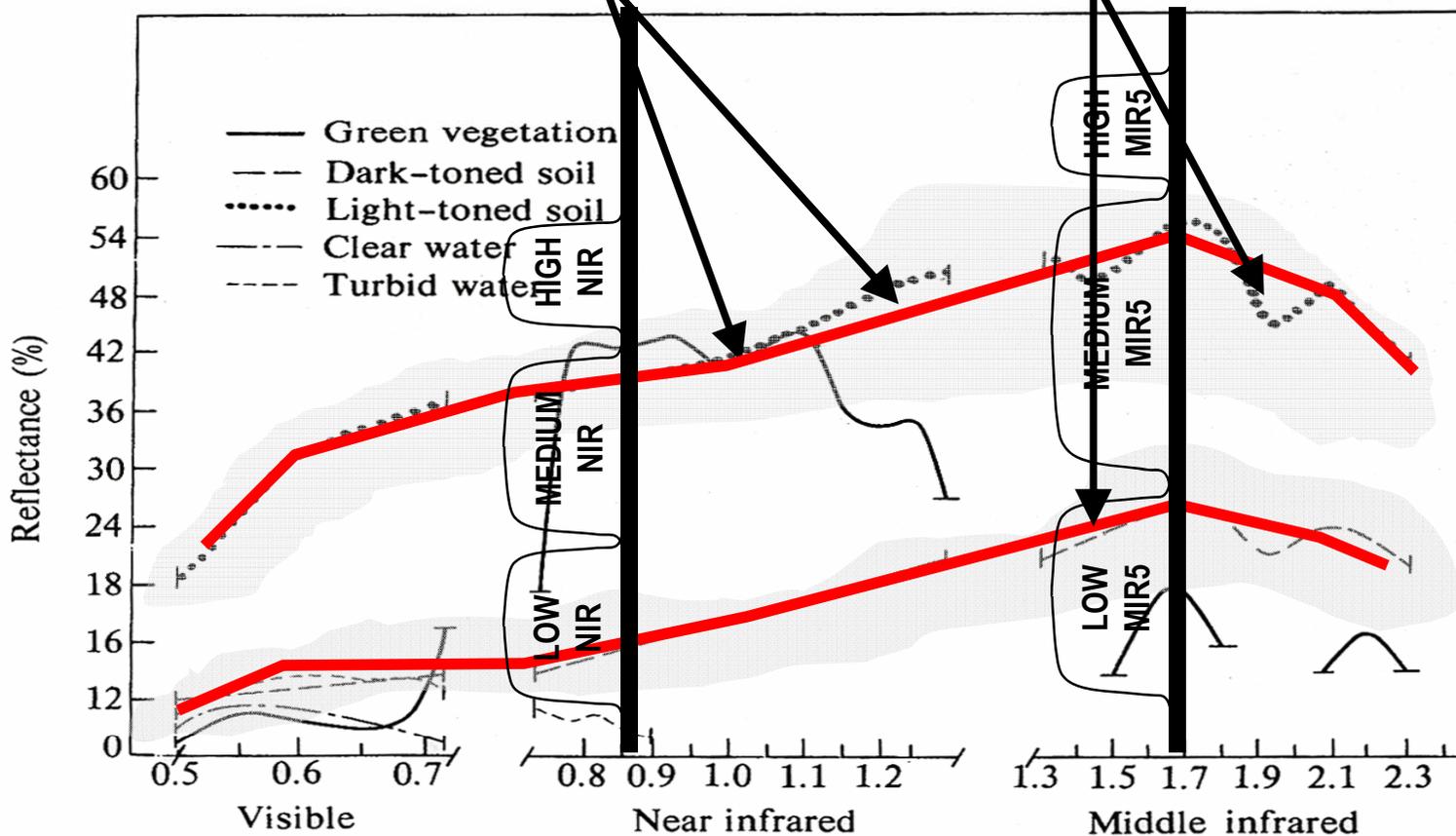


Subset_Carpathian_p186r026	Min	Max	Mean	StDev
ETM1	95	122	110.70	5.40
ETM2	94	120	109.09	5.23
ETM3	99	128	114.74	6.01
ETM4	131	158	146.46	5.18
ETM5	129	159	145.38	6.32
ETM7	99	131	117.35	6.69
ETM62	104	105	104.21	0.41

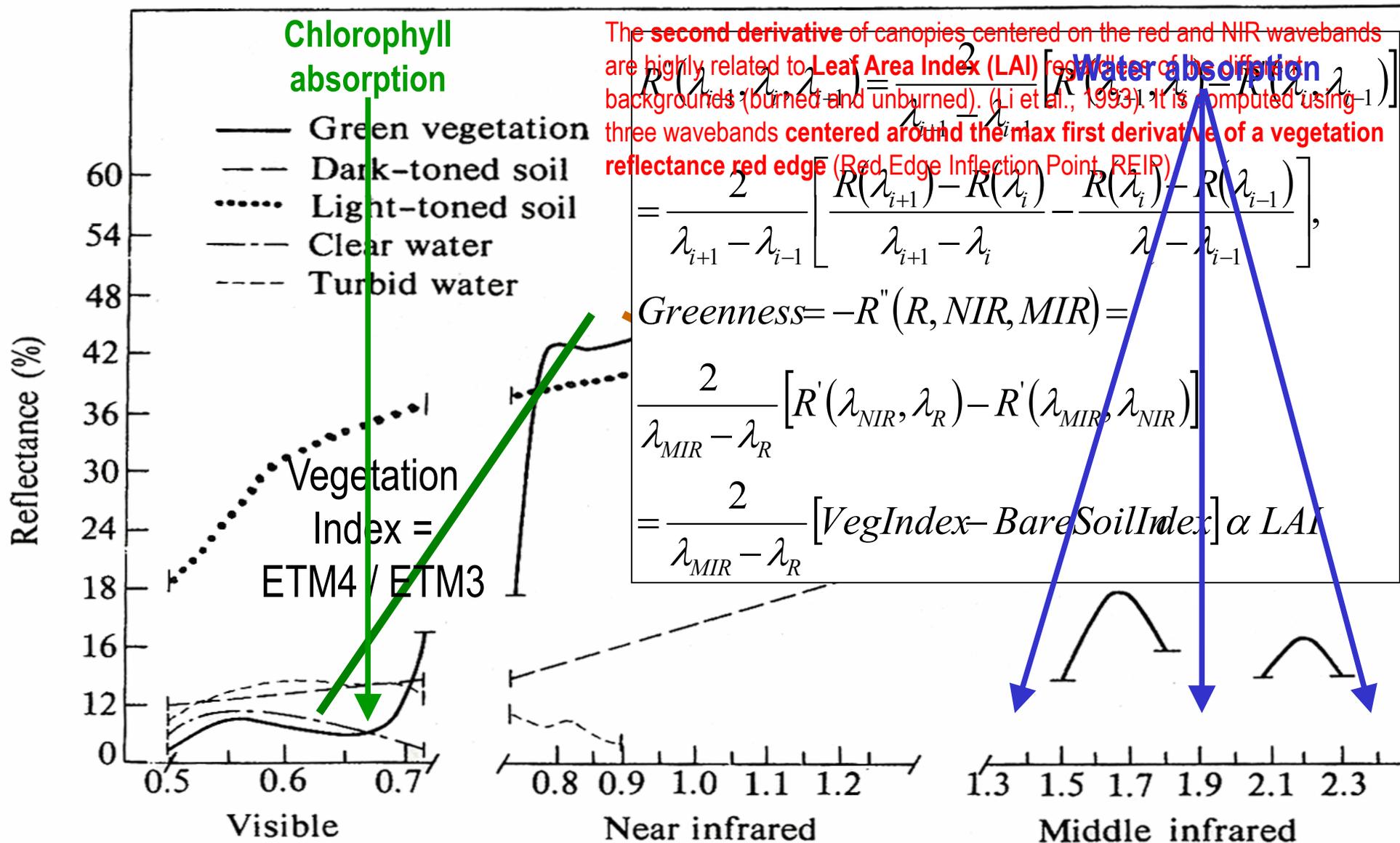
# Rule-based system implementation

**1st LEVEL OF ANALYSIS:**  
 For a given spectral signature (e.g., Barren land), model inter-band fuzzy relationships, e.g.,  $TM5 > (TM4 - 10\%) \pm$

**2nd LEVEL OF ANALYSIS:** Spectral signature quantization through fuzzy sets, e.g., Bright Barren Land and Dark Barren land.



# Operational system properties – Greenness $\propto$ Leaf Area Index (LAI)



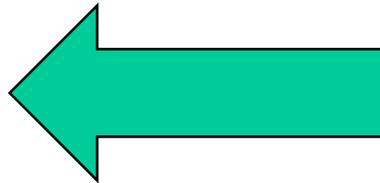
## Classification system scalability to other sensors

**Scalability of the Landsat rule-based classifier to SPOT-4 and -5 (done! From 85 to 59 output categories),  
 ASTER (done! 85 categories) and MODIS (done! 85 categories).**

Landsat 5 TM and 7 ETM+ band	Landsat spectral region (μm)	SPOT-4 and -5 band	SPOT-4 and -5 spectral region (μm)	ASTER band	ASTER spectral region (μm)	MODIS band	MODIS spectral region (μm)
1 (B)	0.45-0.52	-	-	-	-	(3 + 10)	[(0.459 – 0.479) + (0.483 – 0.493)]
2 (G)	0.52-0.60	1	0.50-0.59	1	0.52-0.60	(11 + 4)	[(0.526 – 0.536) + (0.545 – 0.565)]
3 (R)	0.63-0.69	2	0.61-0.68	2	0.63-0.69	(1 + 14)	[(0.620 – 0.670) + (0.673 – 0.683)]
4 (NIR)	0.76-0.90	3	0.79-0.89	3	0.76-0.86	(15 + 2 + 17) OR (15 + 16 + 17)	[(0.743 – 0.753) + (0.841 – 0.876) + (0.890 – 0.920)] OR [(0.743 – 0.753) + (0.862 – 0.877) + (0.890 – 0.920)]
5 (MIR1)	1.55-1.75	4	1.58-1.75	4	1.600-1.700	6	1.628 – 1.652
7 (TIR)	2.08-2.35	-	-	(5 + 6 + 7 + 8)	[(2.145-2.185) + (2.185-2.225) + (2.235-2.285) + (2.295-2.365)]	7	2.105 – 2.155
6 (MIR2)	10.4-12.5	-	-	(13 + 14)	[(10.25-10.95) + (10.95-11.65)]	(31 + 32)	[(10.780 - 11.280) + (11.770 - 12.270)]

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## Operational SIAM™ system of systems' properties

**Integrated SIAM™ system of classifiers, v86r3**

<b>SIAM™ module</b>	<b>Bands</b>	<b>Fine information granularity</b>	<b>Fine information granularity</b>	<b>Fine information granularity</b>	<b>% Loss in spectral category discrimination capability</b>
<b>Landsat-like SIAM™</b>	7 (B, G, R, NIR, MIR1, MIR2, TIR)	95	47	18	-
<b>SPOT-like SIAM™</b>	4 (G, R, NIR, MIR1)	68	40	15	<b>30%</b>
<b>AVHRR-like SIAM™</b>	4 (R, NIR, MIR1, TIR)	82	42	16	<b>14%</b>
<b>IKONOS-like SIAM™</b>	4 (B, G, R, NIR)	52	28	12	<b>44%</b>



## Symbolic (semantic) meaning of spectral categories: Some examples

Spectral category's acronym: water/shadow, cloud, snow/ice, bare soil/built-up, vegetation, outliers.	Spectral category's linguistic description	Candidate land covers (USGS, levels I and II)
SV, AV, WV	Strong/Average/Weak Vegetation.	Forest land (4), (Vegetated) Cropland (21).
SSR, ASR	Strong/Average Shrub Rangeland.	Shrub and brush rangeland (32).
VBBB, BBB, SBB, ABB, WBB, DBB	Very bright/Bright/Strong/Average/Weak/ Dark Built-up and Barren land.	(Non-vegetated) Cropland (21), Urban or built-up land (1), Barren land (7).
TKCL, TNCL	Thick/Thin Clouds.	Clouds.
DPWASH, SLWASH	Deep/Shallow Water and Shadow areas.	Water (5).

# SIAM™ map legend

"Large" leaf area index (LAI) vegetation types (LAI values decreasing left to right)	
"Average" LAI vegetation types (LAI values decreasing left to right)	
Shrub or herbaceous rangeland	
Other types of vegetation (e.g., vegetation in shadow, dark vegetation, wetland)	
Bare soil or built-up	
Deep water, shallow water, turbid water or shadow	
Thick cloud and thin cloud over vegetation, or water, or bare soil	
Thick smoke plume and thin smoke plume over vegetation, or water, or bare soil	
Snow and shadow snow	
Shadow	
Flame	
Unknowns	

**Preliminary classification map legend adopted by L-SIAM™. Pseudo-colors of the 95 spectral categories are gathered based on their spectral end member (e.g., bare soil or built-up) or parent spectral category (e.g., "strong" vegetation). The pseudo-color of a spectral category is chosen as to mimic natural colors of pixels belonging to that spectral category.**

"Large" leaf area index (LAI) vegetation types (LAI values decreasing left to right)	
"Average" LAI vegetation types (LAI values decreasing left to right)	
Shrub or herbaceous rangeland	
Other types of vegetation (e.g., vegetation in shadow, dark vegetation, wetland)	
Bare soil or built-up	
Deep water or turbid water or shadow	
Smoke plume over water, over vegetation or over bare soil	
Snow or cloud or bright bare soil or bright built-up	
Unknowns	

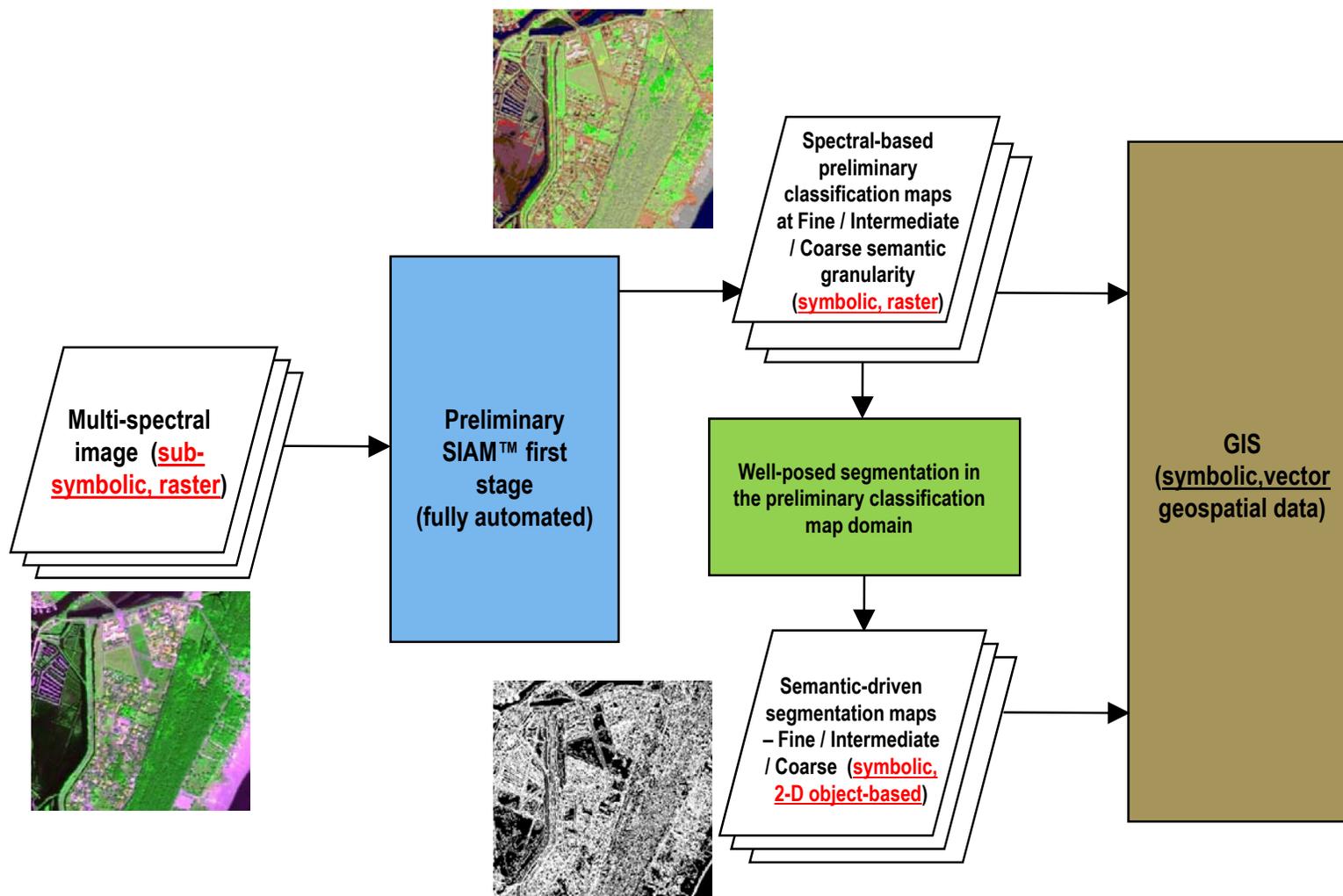
**Preliminary classification map legend adopted by I-SIAM™. Pseudo-colors of the 52 spectral categories are gathered based on their spectral end member (e.g., bare soil or built-up) or parent spectral category (e.g., "strong" vegetation). The pseudo-color of a spectral category is chosen as to mimic natural colors of pixels belonging to that spectral category.**

## SIAM's QIs versus State-of-the-Art RS-IUSs

Legend of fuzzy sets. Very low (VL), Low (L), Medium (M), High (H), Very High (VH)

Quality Indicators (Qis)	State-of-the-art RS-IUSs	SIAM™
<b>Degree of automation:</b> (a) number, physical meaning and range of variation of user-defined parameters, (b) collection of the required training data set, if any.	VL, L	VH (fully automatic, it cannot be surpassed)
<b>Effectiveness :</b> (a) semantic accuracy and (b) spatial accuracy.	M, H, VH	VH
Semantic information level	Land cover class (e.g., <i>deciduous forest</i> )	Spectral semi-concept (e.g., <i>vegetation</i> )
<b>Efficiency:</b> (a) computation time and (b) memory occupation.	VL, L in training (hours per images)	VH (5 m to 30 s per Landsat image in a laptop)
<b>Robustness to changes in input image</b>	VL (specific training per image)	VH
<b>Robustness to changes in input parameters</b>	VL	VH (it cannot be surpassed)
<b>Scalability to changes in the sensor's specifications or user's needs.</b>	VL	VH (it works with any existing spaceborne sensor)
<b>Timeliness</b> (from data acquisition to high-level product generation, increases with manpower and computing power).	VH (e.g., the collection of reference samples is a difficult and expensive task)	VL
<b>Economy</b> (inverse of costs, increasing with manpower and computing power).	VL, L, high costs in manpower and also computing power	VH, almost zero costs

# Seamless integration of RS imagery with GIS through SIAM™



## Application domains 1 and 2.

Baseline map generation / ROI extraction from Landsat 7 ETM+ imagery. Example b: Pakistan.

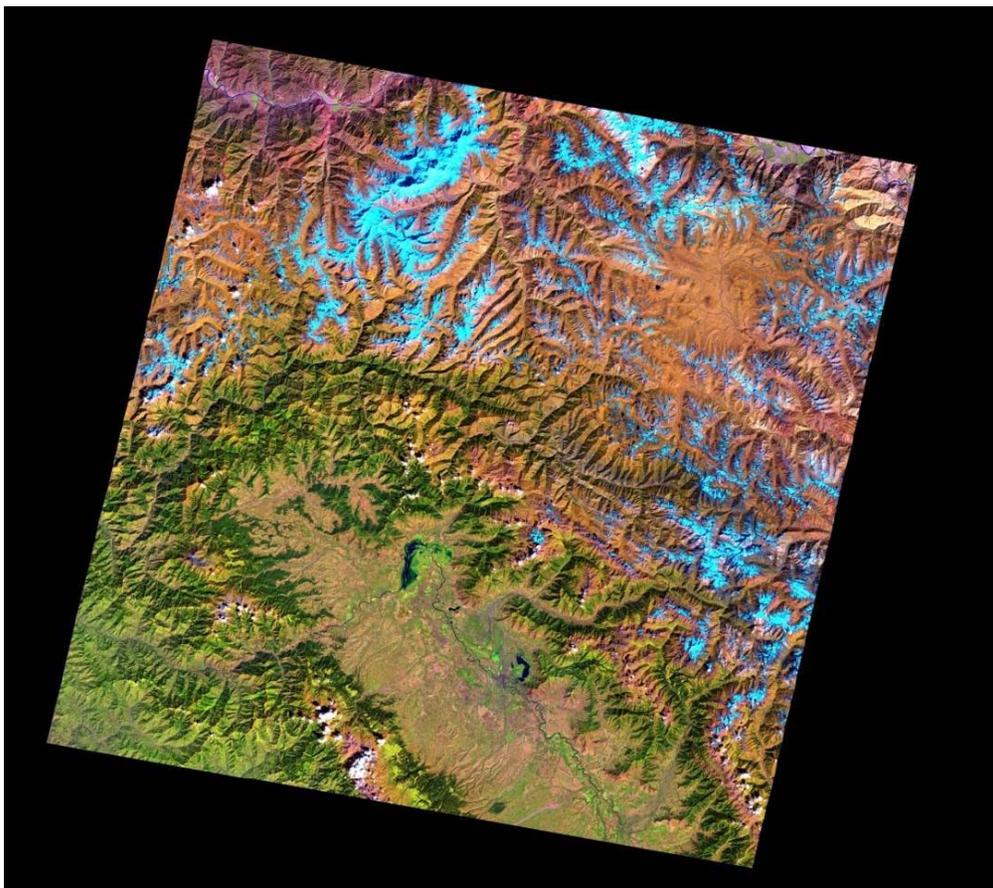


Fig. A. Landsat 7 ETM+ scene. False color image (R: band TM5, G: band TM4, B: band TM1). Path: 149, Row: 036, acquisition date: 2001-09-30, Pakistan.

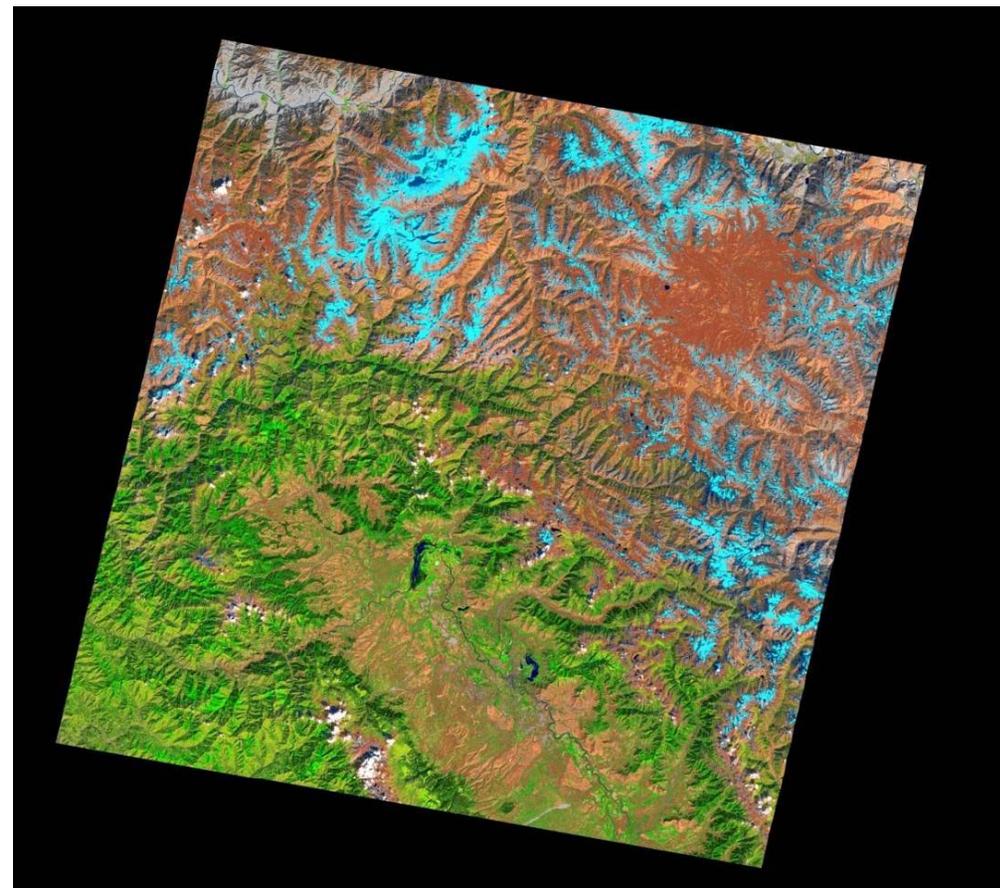


Fig. B. Output map generated from Fig. A, consisting of 45 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White tones: clouds, Light blue tones: snow and ice, etc.

## Zoomed area. Example b: Landsat 7 ETM+, Pakistan.



Fig. C. Zoomed area extracted from Fig. A. False color image (R: band TM5, G: band TM4, B: band TM1). Path: 149, Row: 036, acquisition date: 2001-09-30, Pakistan.



Fig. D. Zoomed area extracted from the 45-class output map shown in Fig. B. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White tones: clouds, Light blue tones: snow and ice, etc.

# Example: Web-Enabled Landsat Data (WELD) Project.

Landsat Missions Página 1 de 3



## Conterminous United States Landsat ETM+ Annual Mosaic

### Web-Enabled Landsat Data (WELD) Project

The Web-Enabled Landsat Data (WELD) project will improve the consistency and quality of Landsat Enhanced Thematic Mapper Plus (ETM+) data through a fusion with MODIS land products to systematically generate "seamless" consistent mosaicked ETM+ data sets with per-pixel quality assessment information and derived land cover characterization at monthly, seasonal, and annual time periods. The resulting high spatial resolution Landsat mosaic products will be generated for the conterminous USA and Alaska for a 7-year period and made freely available to the user community. The WELD project is funded by NASA's Making Earth System Data Records for Use in Research Environments (MEASURE) program.

A preliminary WELD data set is available here, specifically, a 12-month annual composite of the conterminous U.S. generated from ETM+ orthorectified and terrain-corrected data acquired December 2007 to November 2008. In the future, other annual, seasonal, and monthly, mosaic data sets will be made available for evaluation by the user community. The large image below shows the ETM+ red, green, and blue wavelength bands of the annual mosaic, please click on it to see a higher-resolution version.



These data are defined with 30m pixels in the Albers Equal Area projection with standard parallels 22.5°N, 45.5°N, latitude of origin 23°N, and central Meridian 96°W. The data are stored in Hierarchical Data Format (HDF) with HDF internal compression. HDF is a data file format designed by the National Center for Supercomputing Applications to assist users in the storage and manipulation of scientific data across diverse operating systems and machines. For example, it is used to store the standard MODIS products. In this version, each pixel has 14 bands (termed HDF science data sets) storing the information described in the Table. Future product versions will have refined processing and content, most notably atmospheric correction, radiometric/BRDF normalization, improved cloud and ETM+ SCLC gap-filling, and land-cover characterization.

WELD Annual Mosaic Version 1.0 Product Format						
Science Data Set Name	Data Type	Valid Range	Scale Factor	Units	Fill Value	Notes
Band1_TOA_REF	int16	-32767 -- 32767	1.0000	unitless	-32768	Top of atmosphere (TOA) brightness temperature standard formulae and associated with the se
Band2_TOA_REF	int16	-32767 -- 32767	1.0000	unitless	-32768	
Band3_TOA_REF	int16	-32767 -- 32767	1.0000	unitless	-32768	
Band4_TOA_REF	int16	-32767 -- 32767	1.0000	unitless	-32768	
Band5_TOA_REF	int16	-32767 -- 32767	1.0000	unitless	-32768	The conventional ETM+ b

<http://landsat.usgs.gov/WELD.php>

11/01/2010

- <http://landsat.usgs.gov/WELD.php>
- Joint USGS and NASA project
- "Seamless" consistent mosaics of fused Landsat-5 Thematic Mapper (TM), Landsat-7 Enhanced TM Plus (ETM+) and MODIS data
- 663 fixed location tiles. Spatial resolution: 30 m.
- USA and Alaska area coverage
- 7-year period coverage
- Weekly, monthly, seasonal and annual coverage
- Top-of-atmosphere reflectance
- Made freely available to the user community.

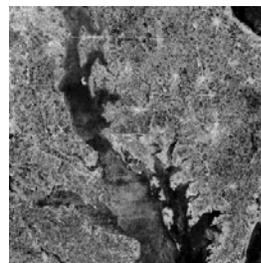
Input image  
In TOA reflectance



Automatic preliminary  
classification (refer to map  
legend)



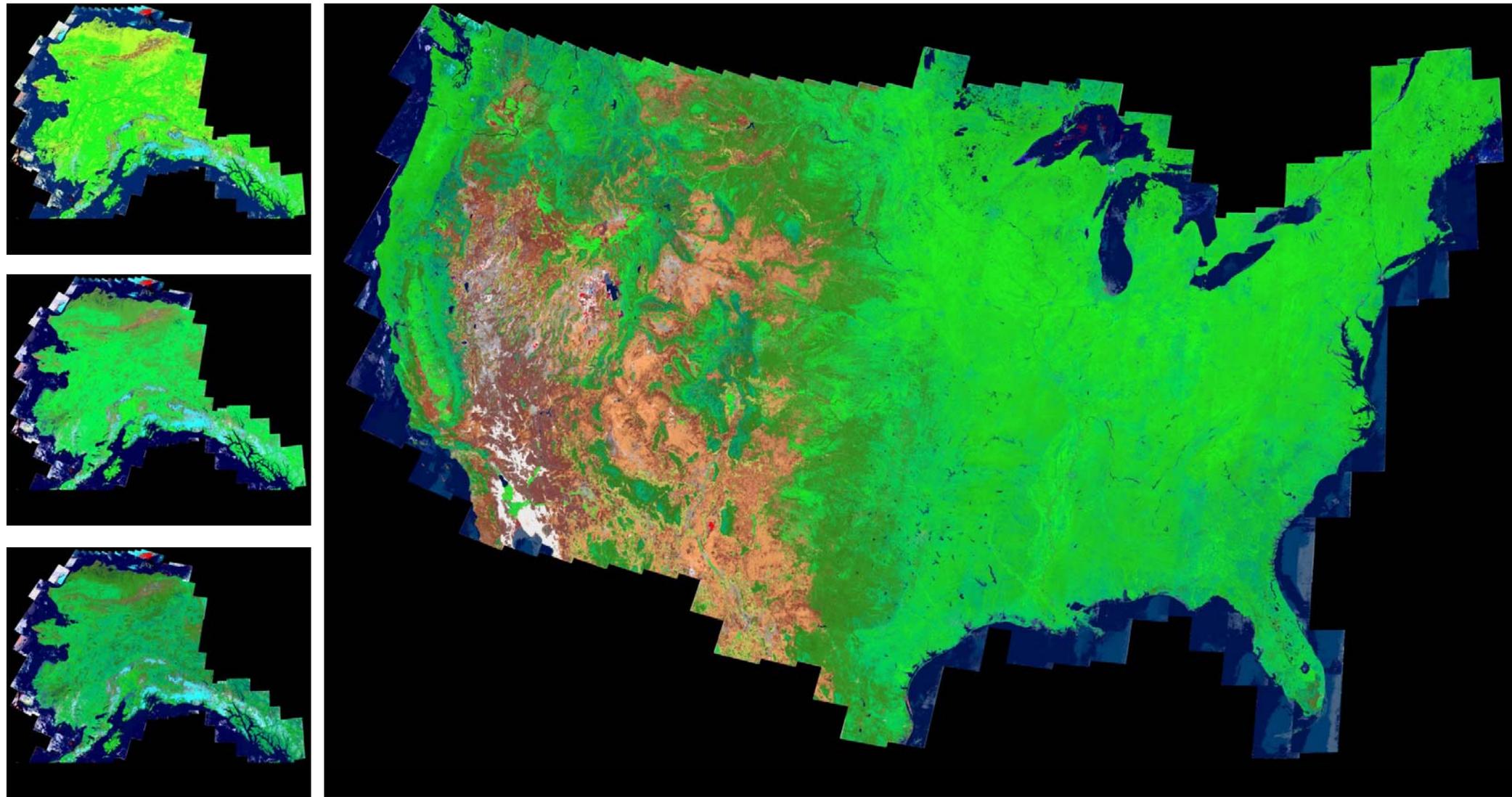
Contour map



Segment-based piecewise  
constant image reconstruction

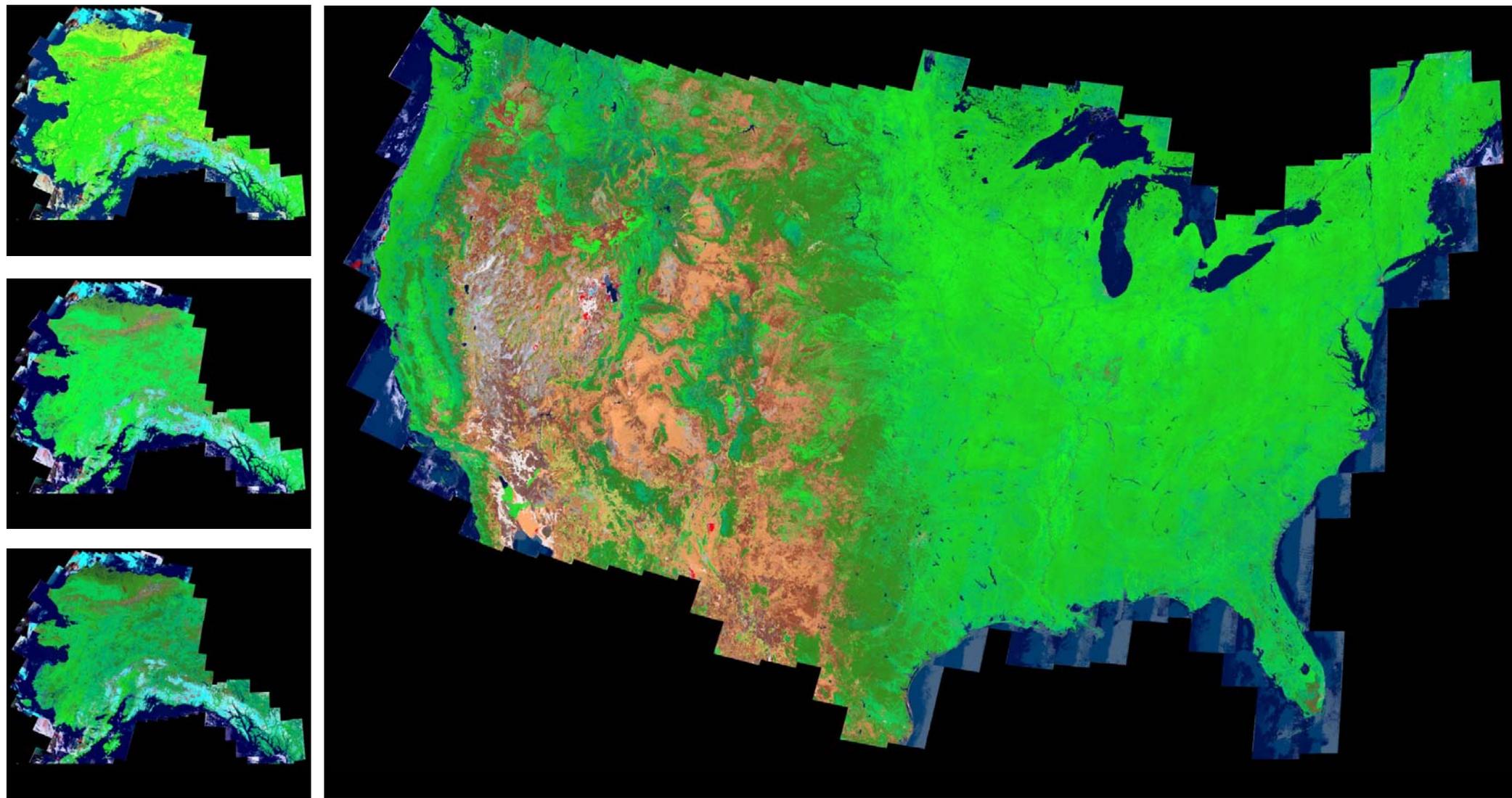


## Example: Web-Enabled Landsat Data (WELD). Year: 2007



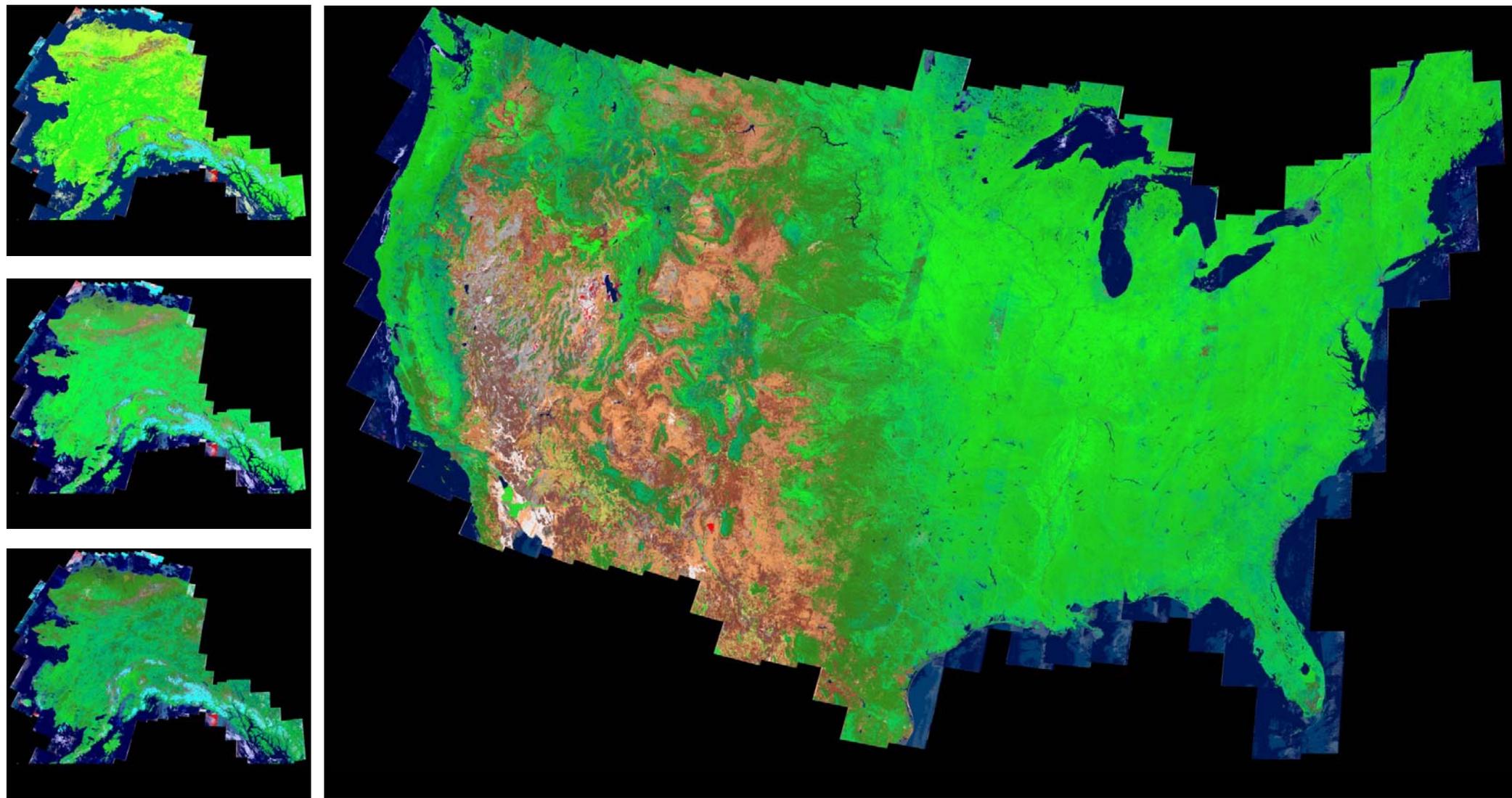
SIAM™ preliminary classification map, depicted in pseudo colors (refer to map legend), generated from the 2007 annual WELD mosaic shown in Fig. 3(a). SIAM™ run by L. Boschetti (Univ. of Maryland), in 1 night of Dec. 2010. Fine: 95 SpCt, Intmedt.: 47 SpCt, Coarse: 18 SpCt.

## Example: Web-Enabled Landsat Data (WELD) Project. Year: 2008



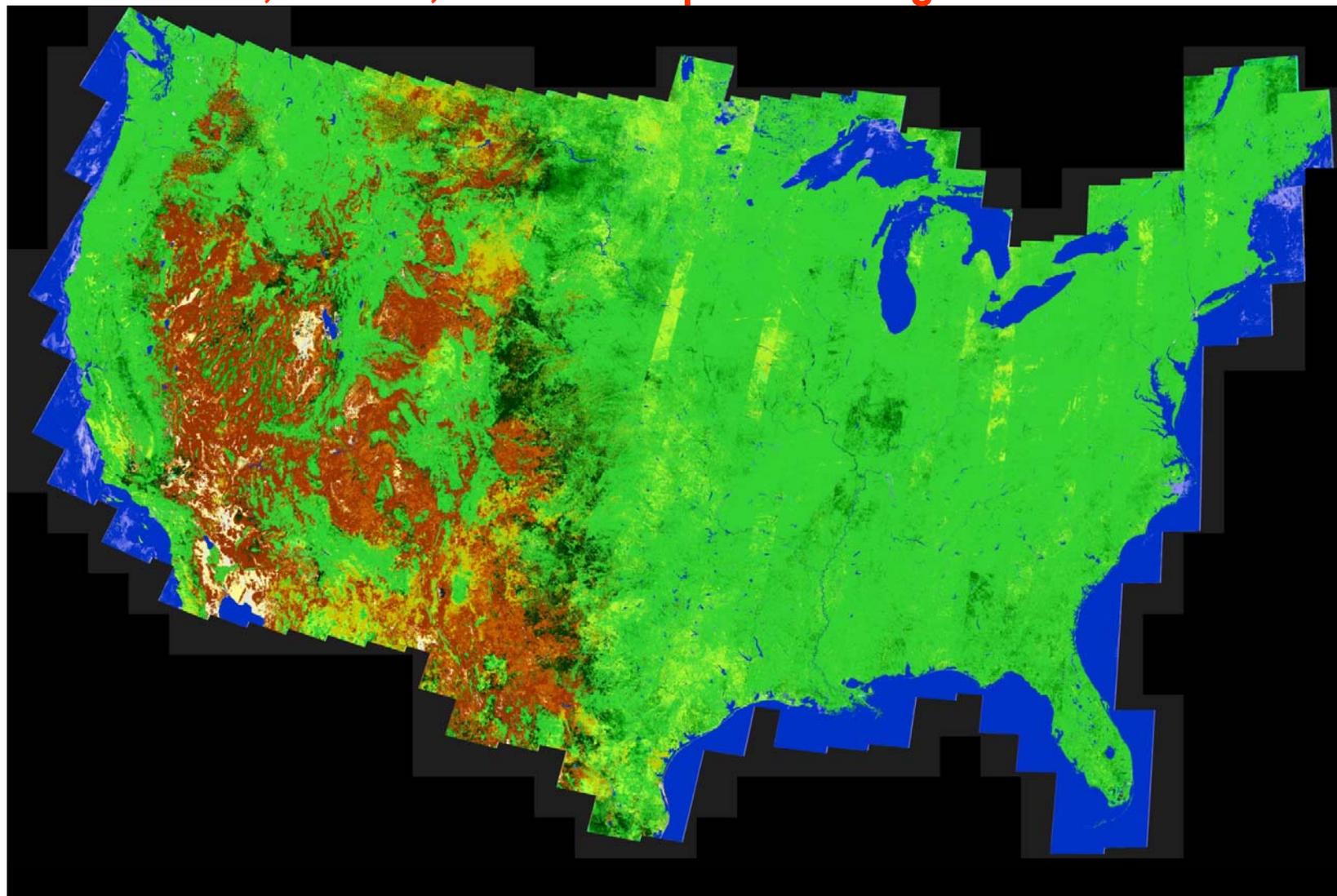
SIAM™ preliminary classification map, depicted in pseudo colors (refer to map legend), generated from the 2008 annual WELD mosaic shown in Fig. 3(a). SIAM™ run by L. Boschetti (Univ. of Maryland), in 1 night of Dec. 2010. Fine: 95 SpCt, Intmedt.: 47 SpCt, Coarse: 18 SpCt.

## Example: Web-Enabled Landsat Data (WELD) Project. Year: 2009



SIAM™ preliminary classification map, depicted in pseudo colors (refer to map legend), generated from the 2009 annual WELD mosaic shown in Fig. 3(a). SIAM™ run by L. Boschetti (Univ. of Maryland), in 1 night of Dec. 2010. Fine: 95 SpCt, Intmedt.: 47 SpCt, Coarse: 18 SpCt.

**Web-Enabled Landsat Data (WELD), Bi-temporal spectral category change detection. Year: 2008-2009, SIAM™, 33 Shared spectral categories.**



- |    |                               |
|----|-------------------------------|
| 1  | Cnstnt Veg                    |
| 2  | Veg Dcrs                      |
| 3  | Veg Incrs                     |
| 4  | Veg Tot Gain from BB or Fire  |
| 5  | Veg Tot Loss into BB          |
| 6  | Veg Tot Gain from WASH        |
| 7  | Veg Tot Loss into WASH        |
| 8  | WASH Tot Loss into BB         |
| 9  | BB Tot Loss into WASH         |
| 10 | Cnstnt or previous (T1) WASH  |
| 11 | Cnstnt BB                     |
| 12 | Within-BB change              |
| 13 | Cnstnt CL                     |
| 14 | Cnstnt or previous (T1) SN    |
| 15 | SN Tot Gain                   |
| 16 | SN Tot Loss                   |
| 17 | Cnstnt or previous (T1) SHSN  |
| 18 | Cnstnt or previous (T1) SH    |
| 19 | Cnstnt or previous (T1) FLAME |
| 20 | Cnstnt UN                     |

Automatic bi-temporal SIAM™-based post-classification change detection, Web-Enabled Landsat Data (WELD). Year: 2008-2009, SIAM™, 33 shared sp. ct.

## Application domains 1 and 2.

Baseline map generation / ROI extraction from SPOT-1 and -2 HRV imagery. Example i: Senegal

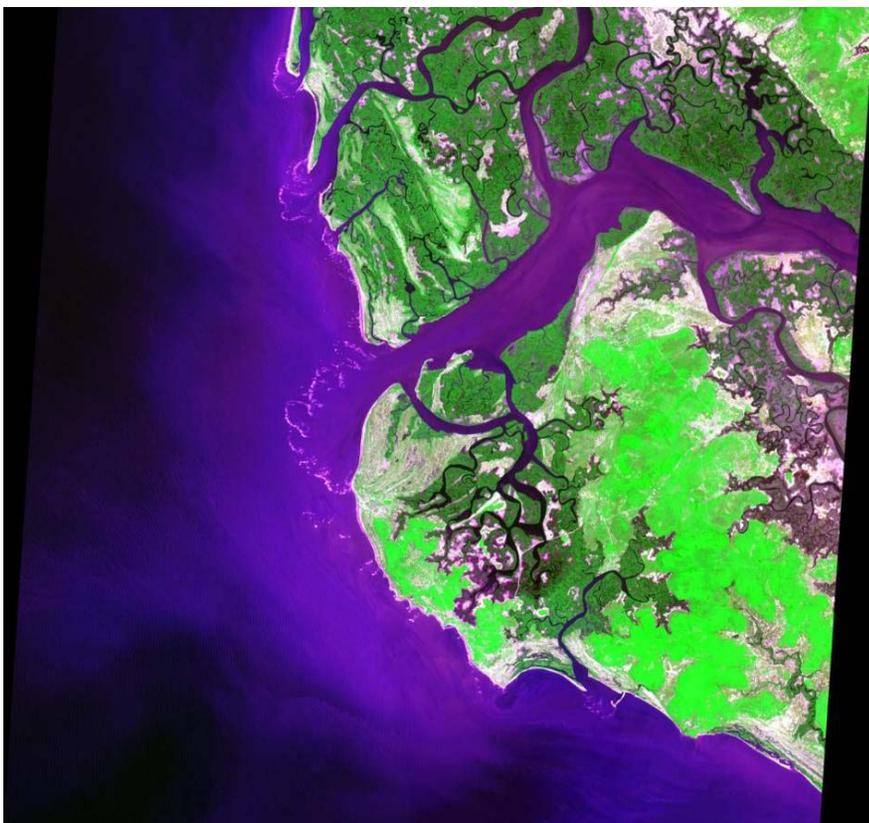


Fig. A. SPOT-2 HRV (High Resolution Visible) scene. False color image (R: band 3, G: band 2, B: band 1). Acquisition date: 2006-03-01, Senegal, spatial resolution: 20m.

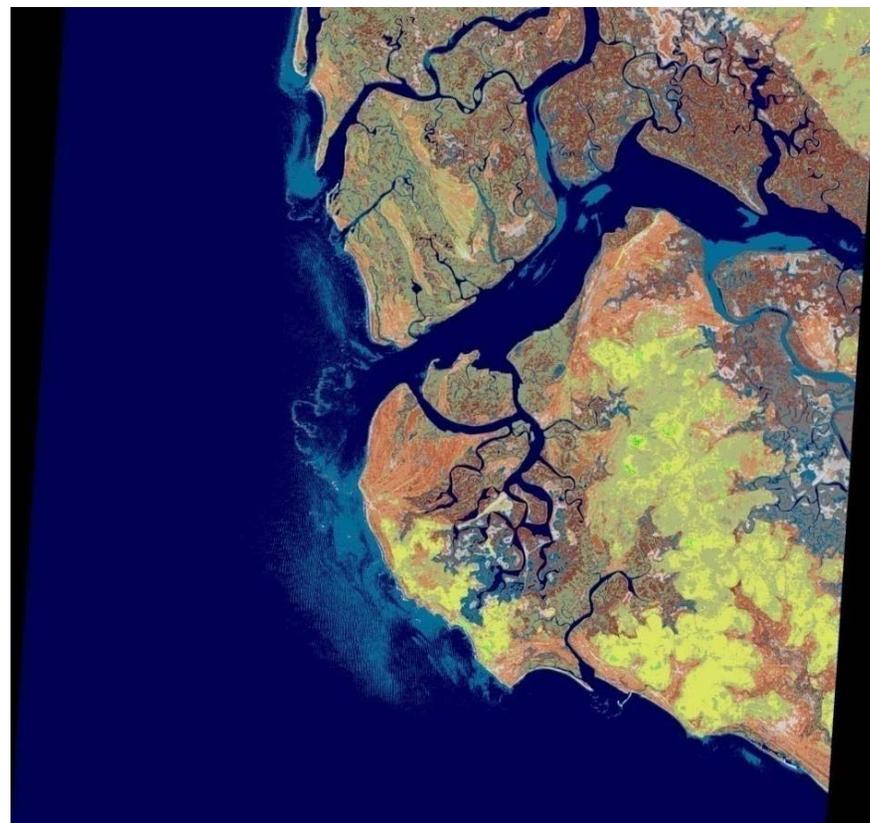


Fig. B. Output map generated from Fig. A, consisting of 46 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, etc.

# Application domains 1 and 2.

Baseline map generation / ROI extraction from IRS-P6 AWiFS imagery. Example m: Greece.



Fig. A. IRS-P6 AWiFS Image acquired on Sept., 2007, covering a surface area in Greece (R: band 4, G: band 3, B: band 1), spatial resolution: 56 m.

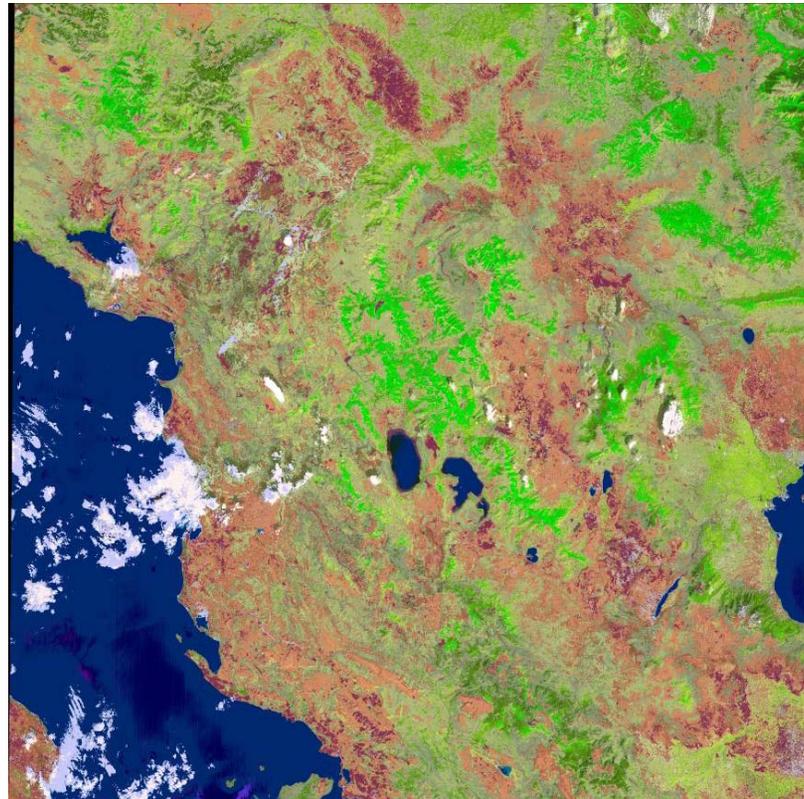
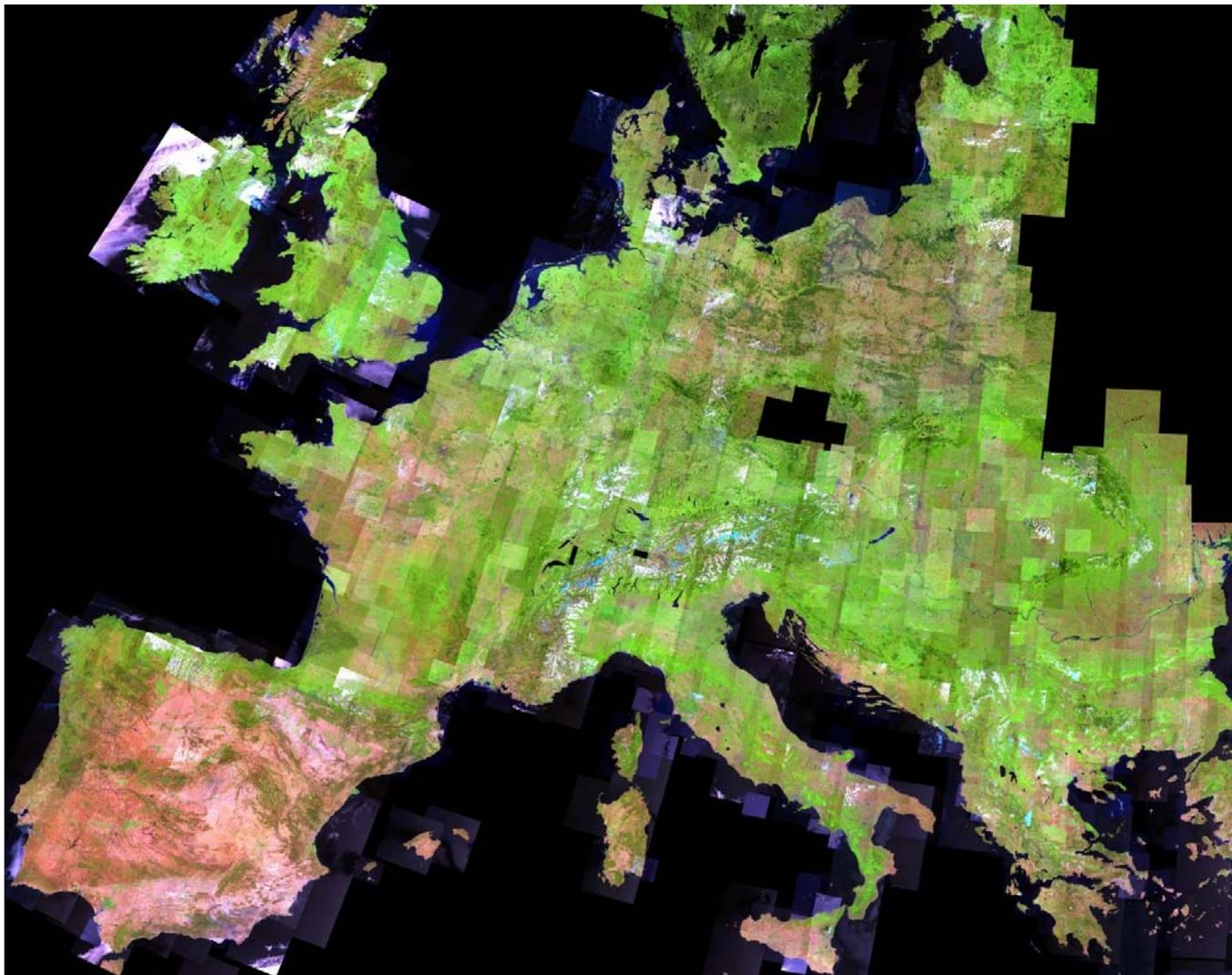


Fig. B. Output map generated from Fig. A, consisting of 62 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

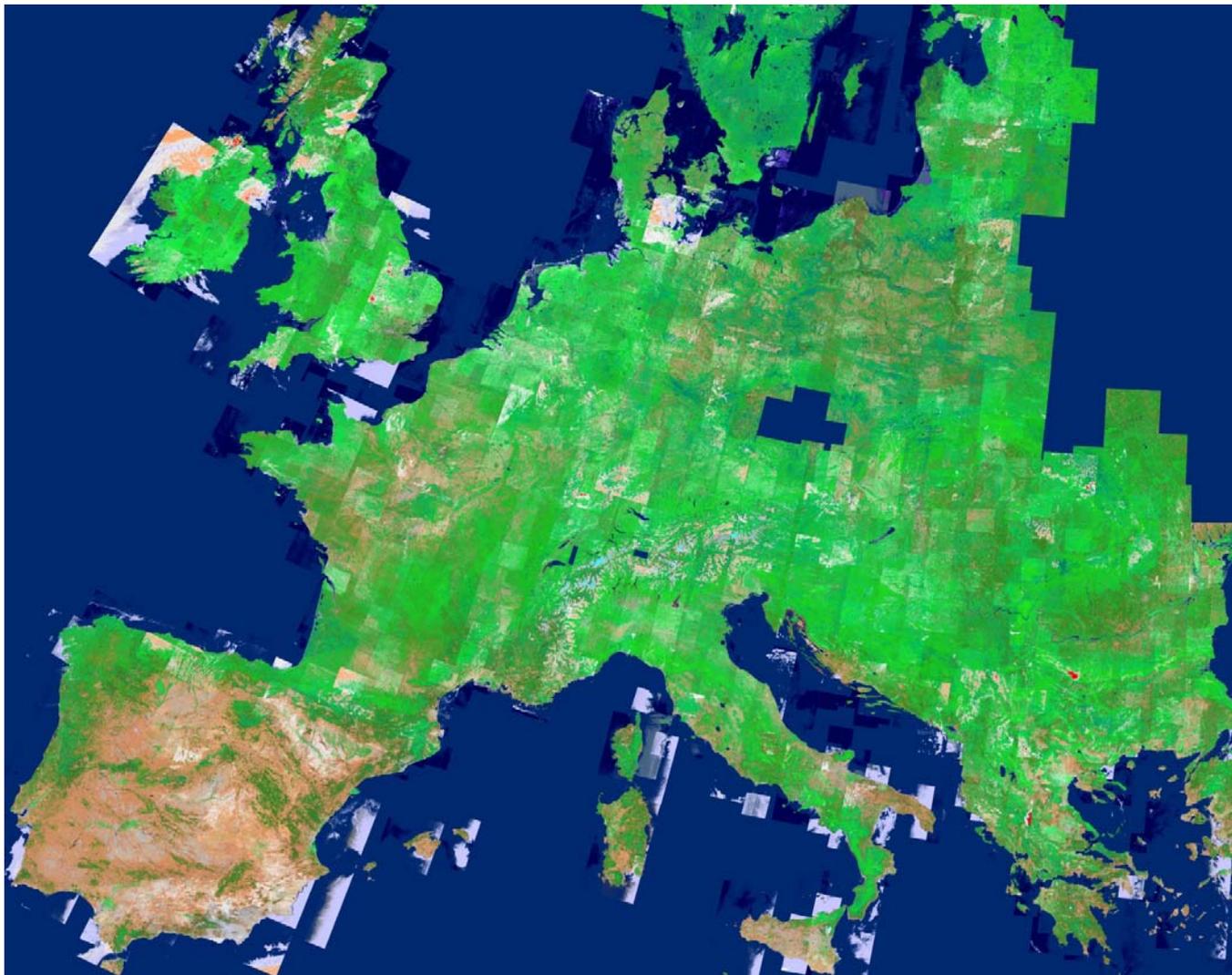
## Application domains 1 and 2. Image 2006 project.



**Image2006 Coverage 1 Mosaic and Value Added Products.**

**Image 2006 Coverage 1 mosaic, consisting of IRS-P6 LISSIII, SPOT-4, and SPOT-5 images, mostly acquired during 2006, radiometrically calibrated into top-of-atmosphere reflectance values and geometrically orthorectified. Images are depicted in false colors: Red – Band 4 (Short Wave InfraRed, SWIR), Green – Band 3 (Near IR, NIR), Blue – Band 1 (Visible Green).**

## Application domains 1 and 2. Image 2006 project.



### Image2006 Coverage 1 Mosaic and Value Added Products.

Fully automated preliminary spectral classification of the Image2006 Coverage 1 mosaic, consisting of 59 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland. Brown and grey tones: barren land and built-up areas. Blue tones: water types. Light blue and white: thin (stratus) and thick (cumulus) clouds.

## Application domains 1 and 2.

Baseline map generation / ROI extraction from MODIS imagery. Example n: Italy

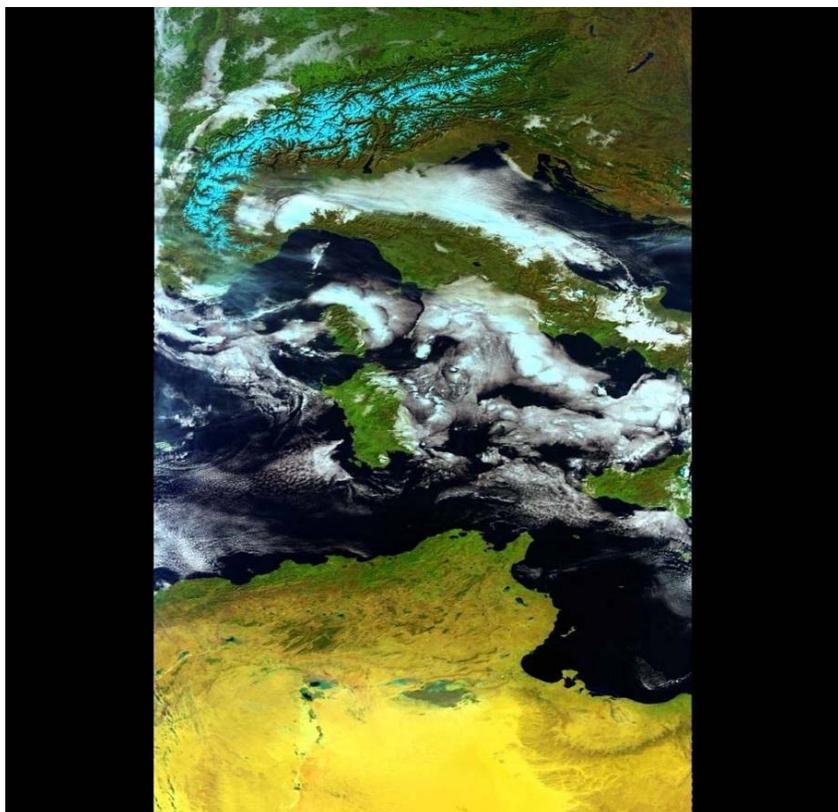


Fig. A. MODIS Image acquired on Jan. 5, 2007, covering northern Africa and Italy (R: band 1, G: band 4, B: band 3), spatial resolution: 1km.

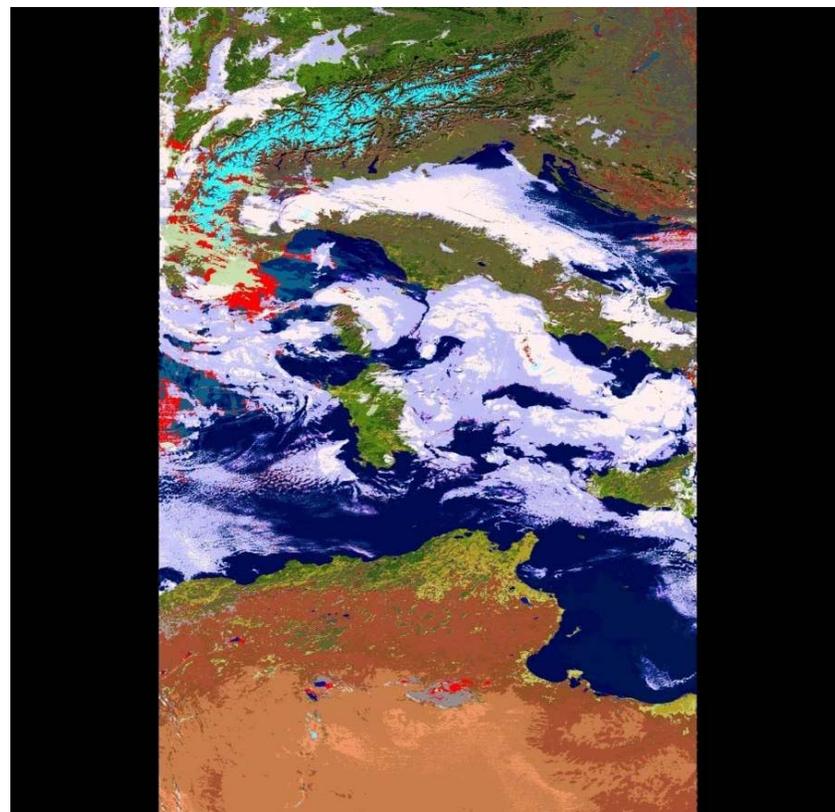


Fig. B. Output map generated from Fig. A, consisting of 72 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

## Application domains 1 and 2.

Baseline map generation / ROI extraction from NOAA-AVHRR imagery. Example o: Italy.

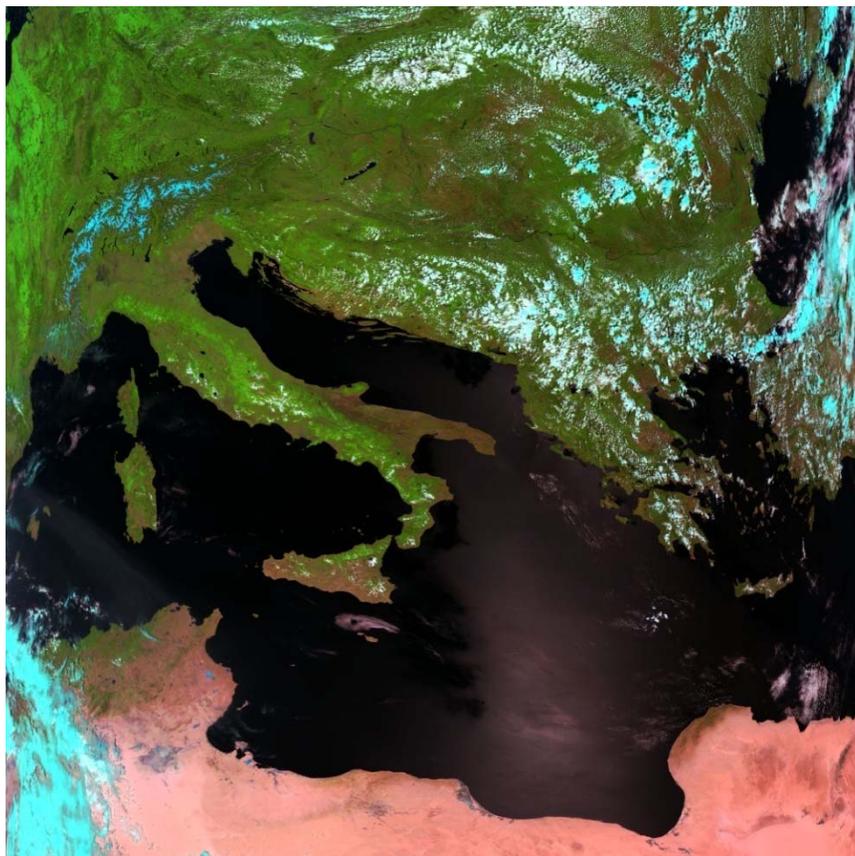


Fig. A. NOAA-AVHRR (Sat. 17) image acquired on 2004-06-08 covering Mediterranean and Balcanic areas (R: band 3a, G: band 2, B: band 1), spatial resolution: 1.1 km.

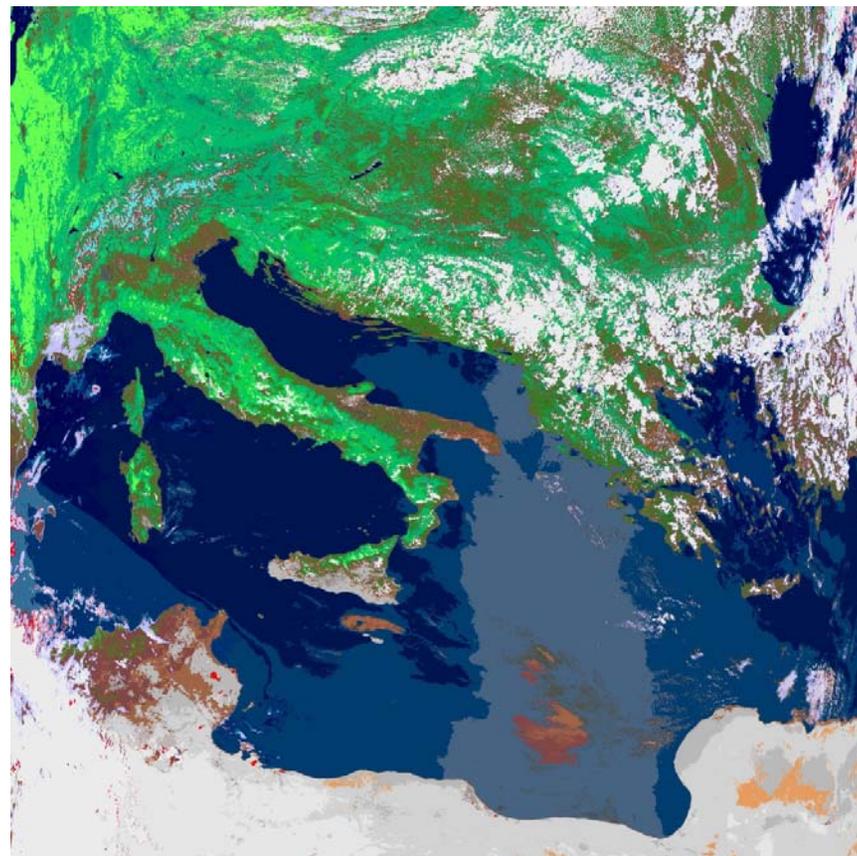


Fig. B. Output map generated from Fig. A, consisting of 82 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

## Application domains 1 and 2.

Baseline map generation / ROI extraction from ENVISAT AATSR imagery. Example p: Black sea.

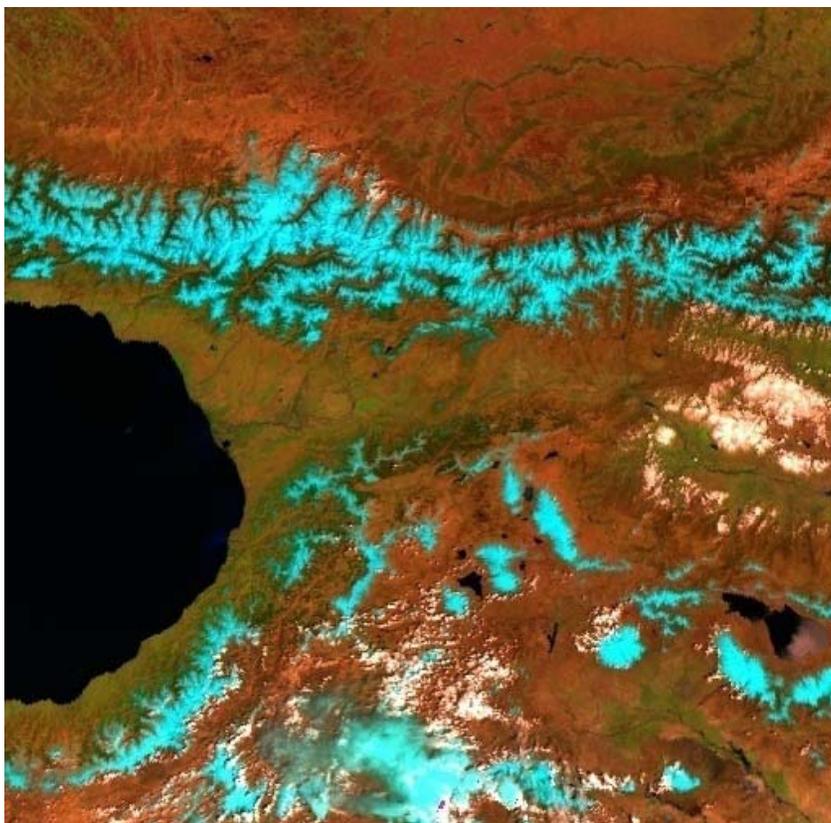


Fig. A. ENVISAT AATSR image acquired on 2003-01-05, covering a surface area over the Black sea (R: band 7, G: band 6, B: band 4), spatial resolution: 1 km.

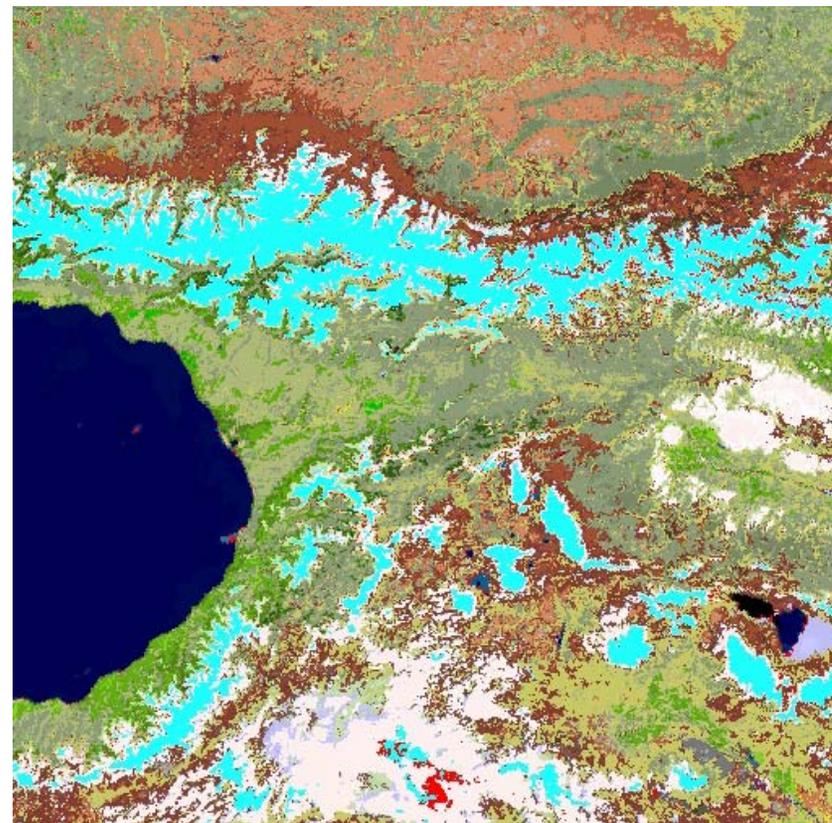


Fig. B. Output map generated from Fig. A, consisting of 72 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

## Application domains 1 and 2.

Baseline map generation / ROI extraction from MSG imagery. Example p: Africa.

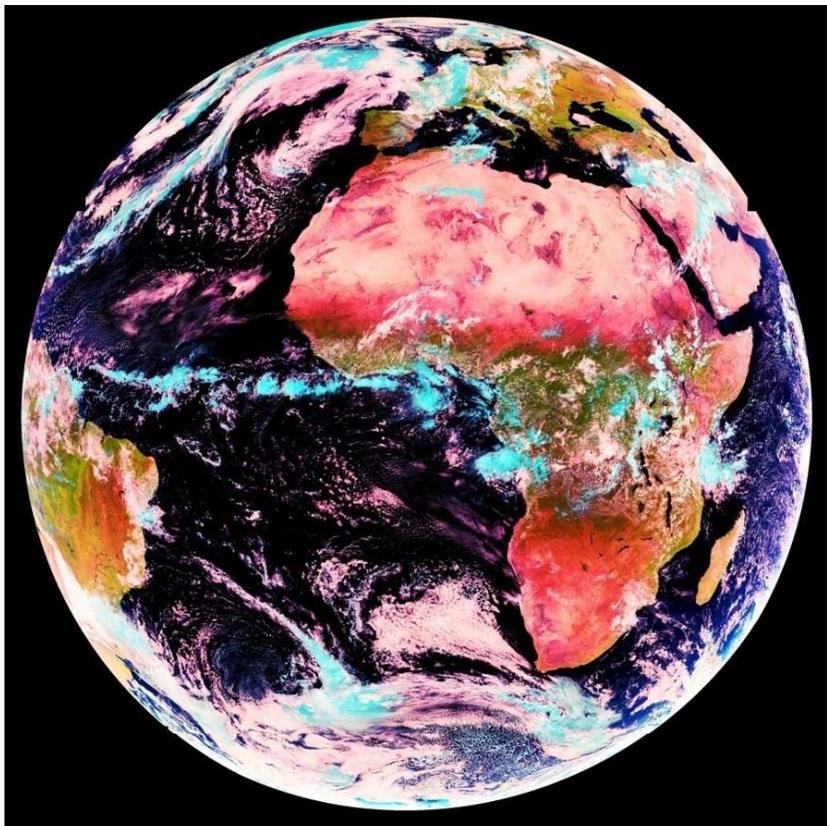


Fig. A. Meteosat 2<sup>nd</sup> Generation (MSG) image acquired on May 16, 2007, at 12.30 (CEST), covering Africa (R: band 3, G: band 2, B: band 1), spatial resolution: 3 km.



Fig. B. Output map generated from Fig. A, consisting of 49 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White and light blue: cloud types, etc.

## Application domains 1 and 2.

Baseline map generation / ROI extraction from IKONOS-like imagery. Example q: Bologna, Italy (synthetic IKONOS from Landsat 7 ETM+).

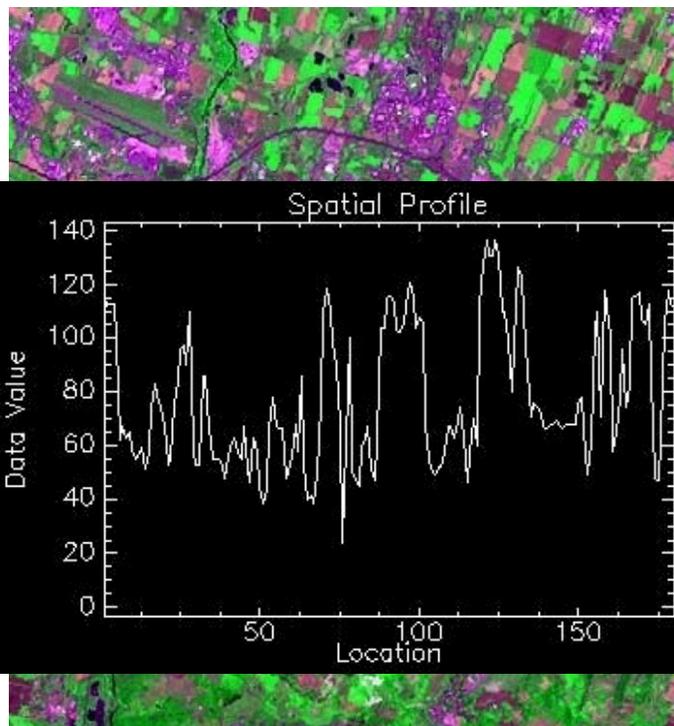


Fig. A. Simulated IKONOS- and QuickBird-like 4-band image generated from a Landsat 7 ETM+ image of the Italian city of Bologna, Italy, acquired on June 20, 2000 (R: band 3, G: band 4, B: band 1), spatial resolution: 30 m.



Fig. B. Output map generated from Fig. A, consisting of 31 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types.

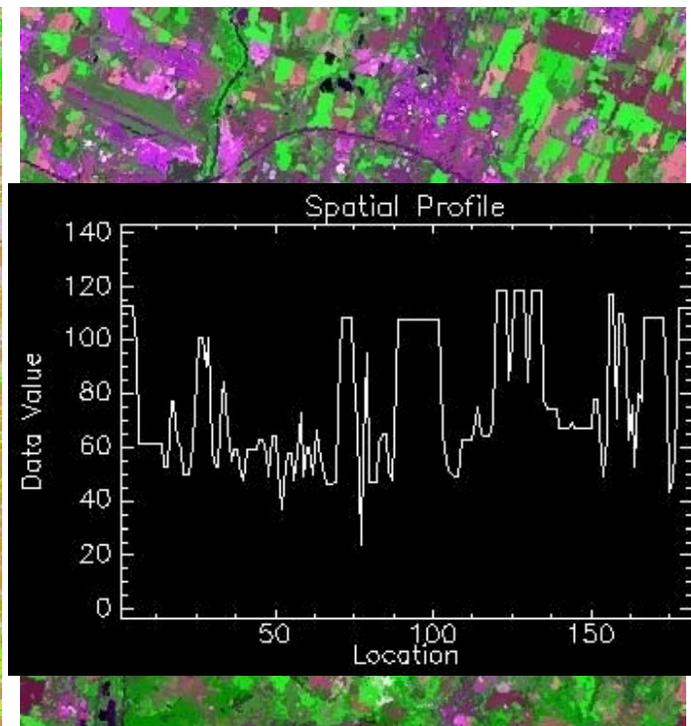


Fig. C. Piecewise constant approximation of Fig. A based on segments extracted from Fig. B, such that each segment is replaced with its mean reflectance value.

## Application domains 1 and 2.

Baseline map generation / ROI extraction from WorldView-2 imagery. Example r: Brazilia, Brazil.



Fig. A. 8-band WorldView-2 VHR image of the city of Brazilia, Brazil, acquired on 2010-08-04, at 13:32 p.m., depicted in false colors (R: band R, G: band NIR1; B: band B) (provided by DigitalGlobe, 8-Band Challenge), calibrated into TOA reflectance. Spatial resolution: 2.0 m.



Fig. B. Output map generated from Fig. A, consisting of 52 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types.

## Application domains 1 and 2.

Baseline map generation / ROI extraction from QuickBird-2 imagery. Example r: Brazilia, Brazil.



Fig. A. 8-band WorldView-2 VHR image of the city of Brazilia, Brazil, acquired on 2010-03-16, at 13:25 p.m., depicted in false colors (R: band R, G: band NIR1; B: band B) (provided by DigitalGlobe, 8-Band Challenge), calibrated into TOA reflectance. Spatial resolution: 2.4 m.

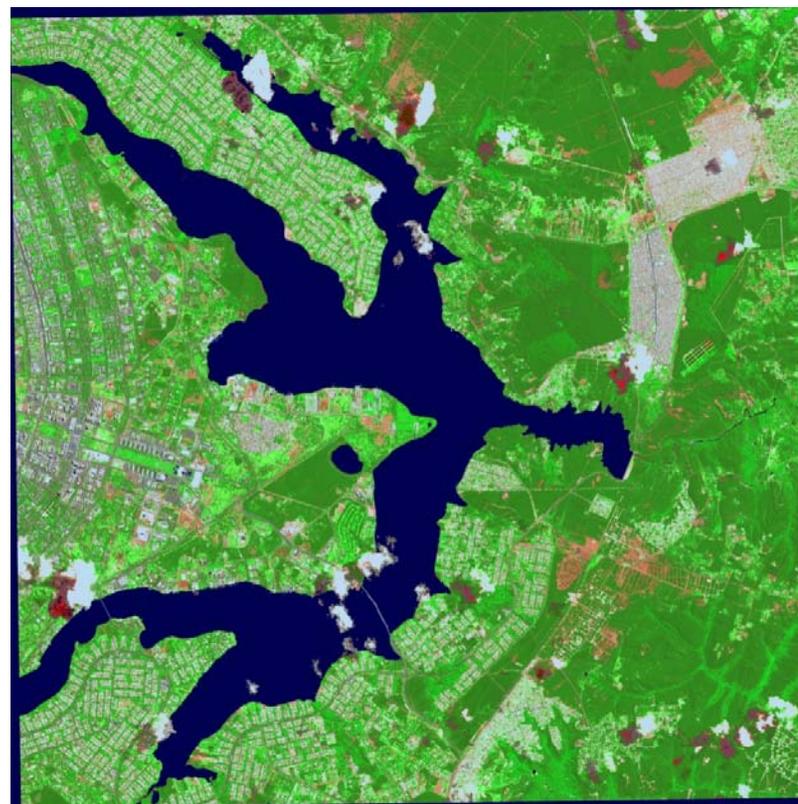


Fig. B. Output map generated from Fig. A, consisting of 52 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types.

## Application domains 1 and 2.

Baseline map generation / ROI extraction from ALOS AVNIR-2. Example q: Sicily, Italy.

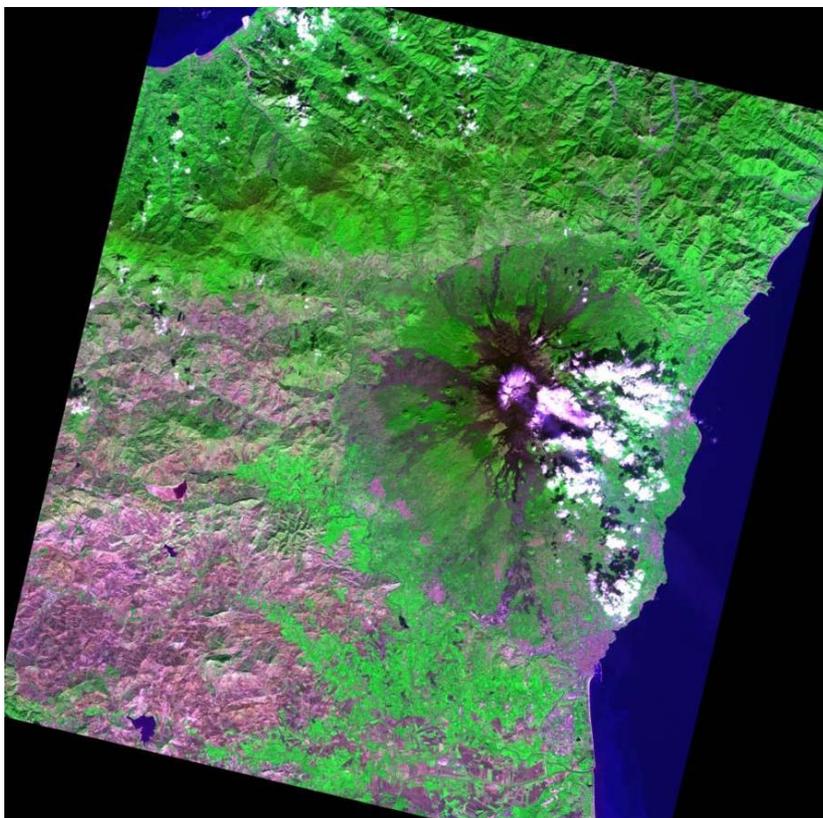


Fig. A. ALOS AVNIR-2 image of Sicily, Italy (acquisition date: 2004-13-06, 09:58 GMT), depicted in false colors (R: band CH3, G: band CH4, B: band CH1), 10m resolution, calibrated into TOA reflectance.

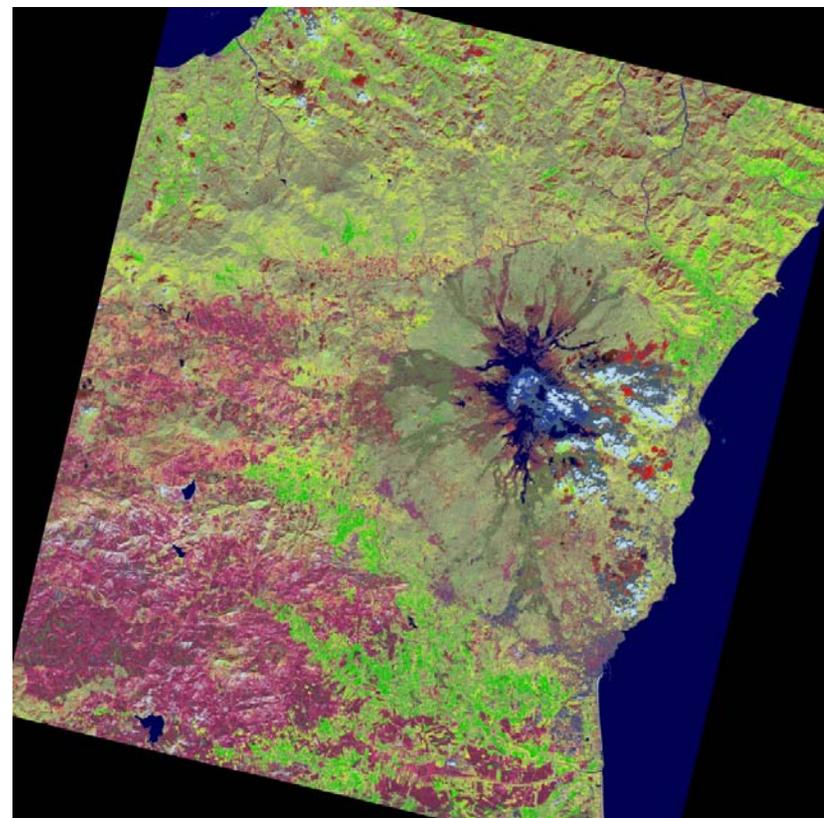


Fig. B. Output map generated from Fig. A, consisting of 46 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types.

## Application domains 1 and 2.

Baseline map generation / ROI extraction from RapidEye. Example q: Dallas, Texas.

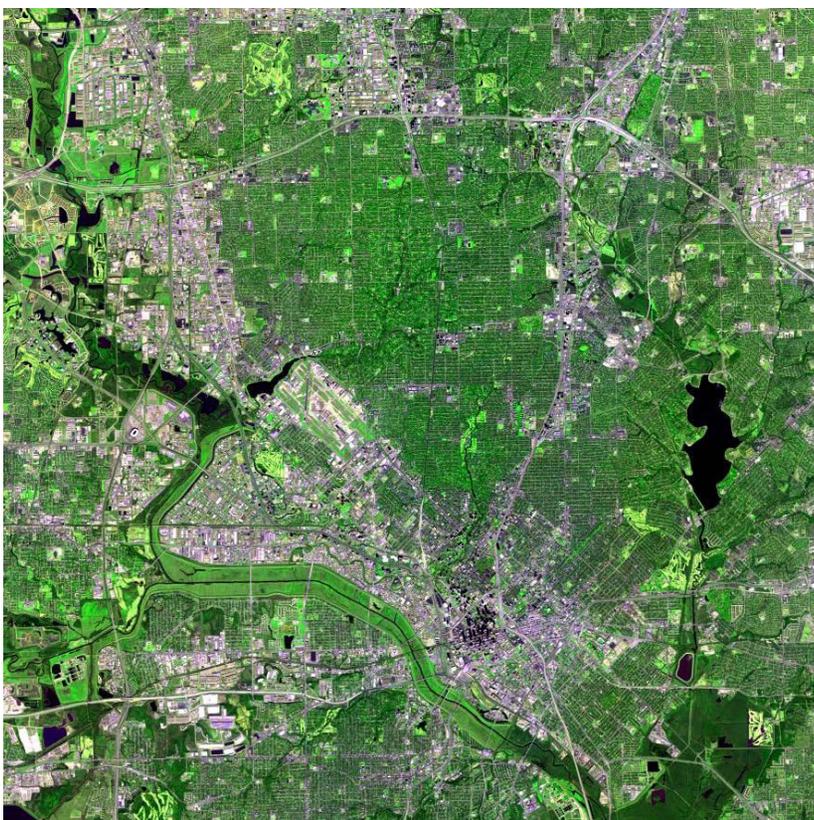


Fig. A. RapidEye image of Dallas, Texas (acquisition date: 2009-02-04, 17:54 GMT), depicted in false colors (R: band CH3, G: band CH5, B: band CH1), 5 m resolution, calibrated into TOA reflectance.

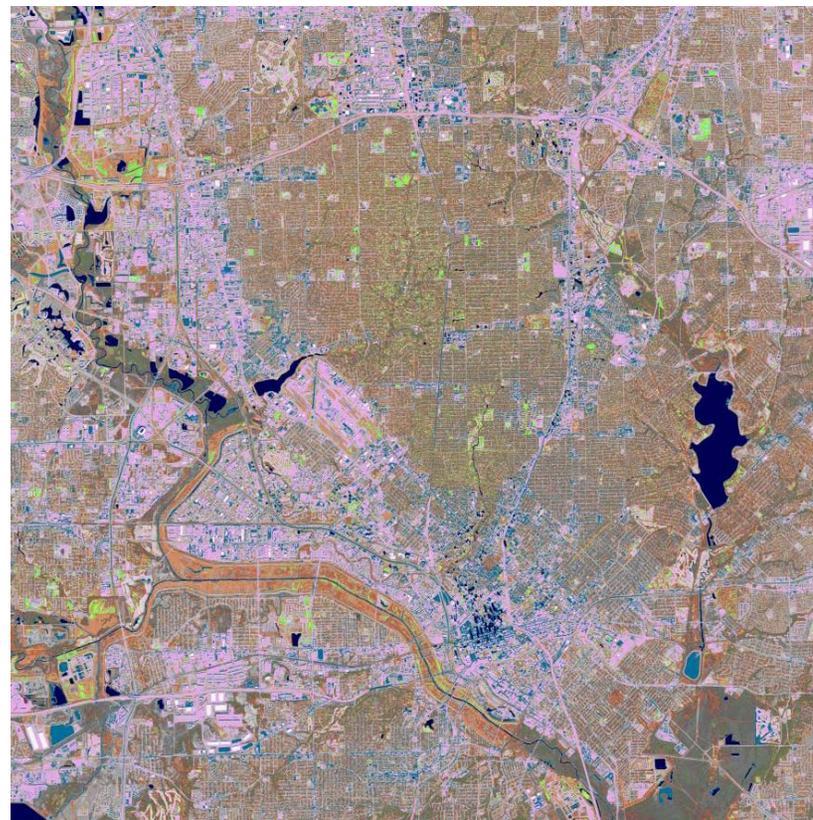


Fig. B. Output map generated from Fig. A, consisting of 50 spectral categories. Adopted pseudo colors are the following. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types.

## Application domain 3.b.

Stratified histogram matching (e.g., in image mosaicking).

Mosaic of 4 rad. calibrated Landsat 7 ETM+ images: Emilia, Romagna, Veneto, Friuli.



Preliminary classification (SIAM™)

Stratified histogram matching

Master image: Veneto image

Slave image: Romagna image.

Target spectral strata: vegetation types, bare soil types, water types.

Preliminary classification (SIAM™)

Mosaic of 4 spectral classification maps, 85 classes.



Mosaic of 4 spectral classification maps, 85 classes.



Mosaic of 4 histo.-matched and rad. calibrated Landsat 7 ETM+ images: Emilia, Romagna, Veneto, Friuli.



## Application domain 3.b. Stratified cloud detection.

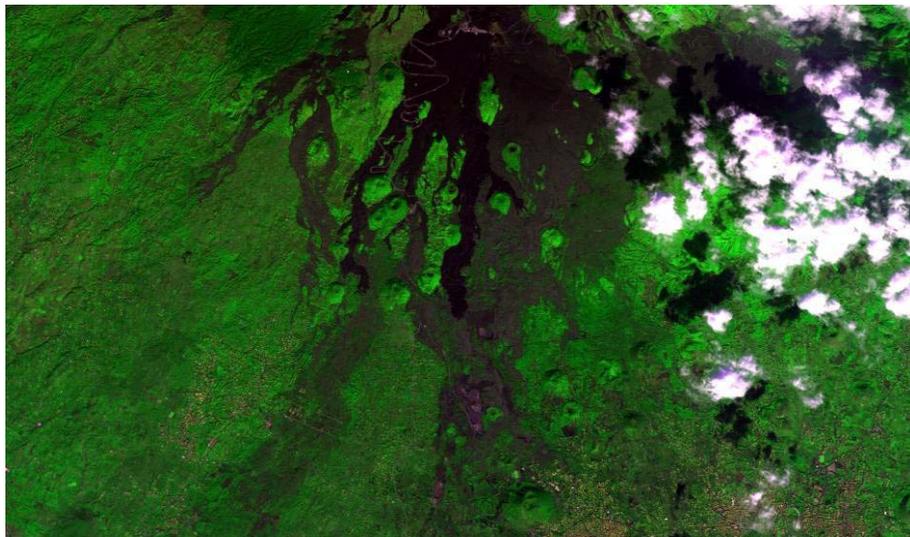


Fig. A. AVNIR-2 ALAV2A041622840 image of Sicily in false colors (R: band 2, G: band 4, B: band 1). Path: ..., Row: ..., acquisition date: YYYY-MM-DD.

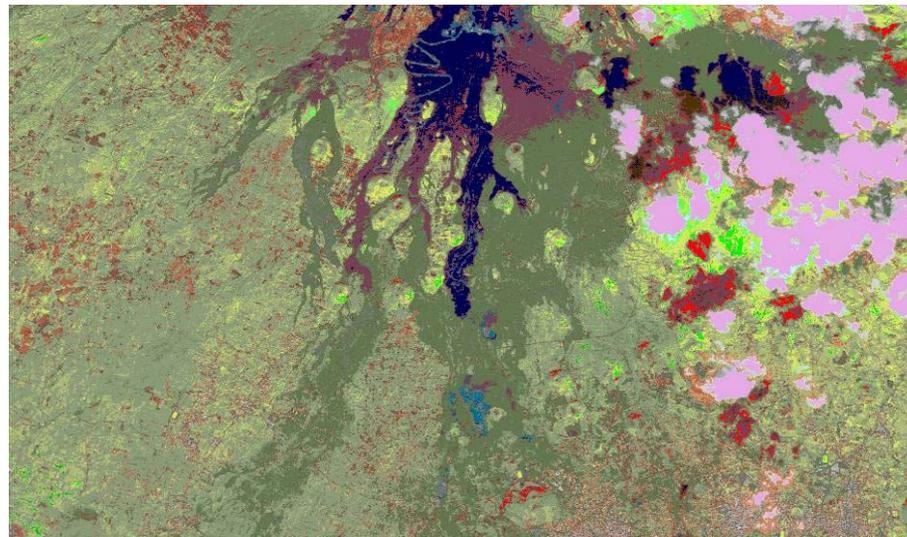


Fig. B. Preliminary classification map generated from Fig. A., consisting of 46 spectral categories.



Fig. C. Binary cloud mask generated from Fig. B, based on segment-based color and geometric properties plus spatial topological relationships (e.g., adjacency, inclusion).

## Application domain 3.e.

Stratified image classification. Example: agricultural field/ broadleaf forest /needleleaf forest



Fig. A. A zoomed area of a Landsat 7 ETM+ image of Virginia, USA (path: 16, row: 34, acquisition date: 2002-09-13), depicted in false colors (R: band ETM5, G: band ETM4, B: band ETM1), 30 m resolution, calibrated into TOA reflectance.

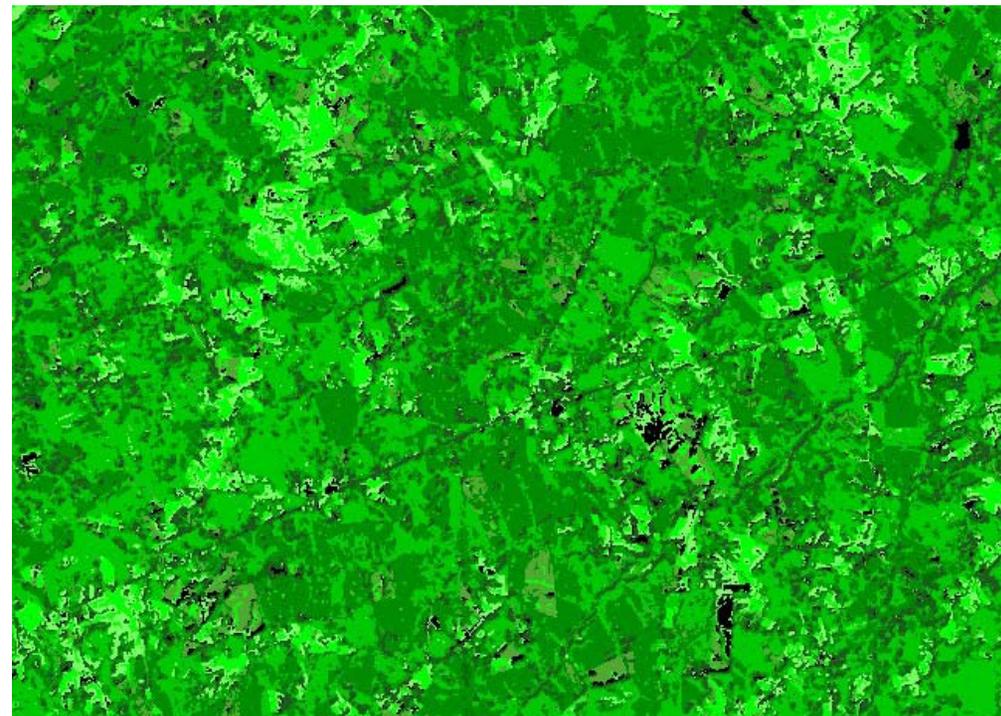


Fig. B. 2<sup>nd</sup>-stage classification map generated in series with the SIAM first stage from Fig. A. This 2<sup>nd</sup>-stage map consists of 11 vegetated land cover classes (in black: non-vegetated pixels), depicted in pseudo-colors, including: crop field or grassland, broad-leaf forest and needle-leaf forest. Input features are: colors (mapped by SIAM™ into a discrete and finite set of spectral categories), brightness and multi-scale isotropic texture.

## Application domain 3.b. Stratified topographic correction.



Fig. A. Zoomed area of a Landsat 7 ETM+ image of Colorado, USA (path: 128, row: 021, acquisition date: 2000-08-09), depicted in false colors (R: band ETM5, G: band ETM4, B: band ETM1), 30m resolution, calibrated into TOA reflectance.

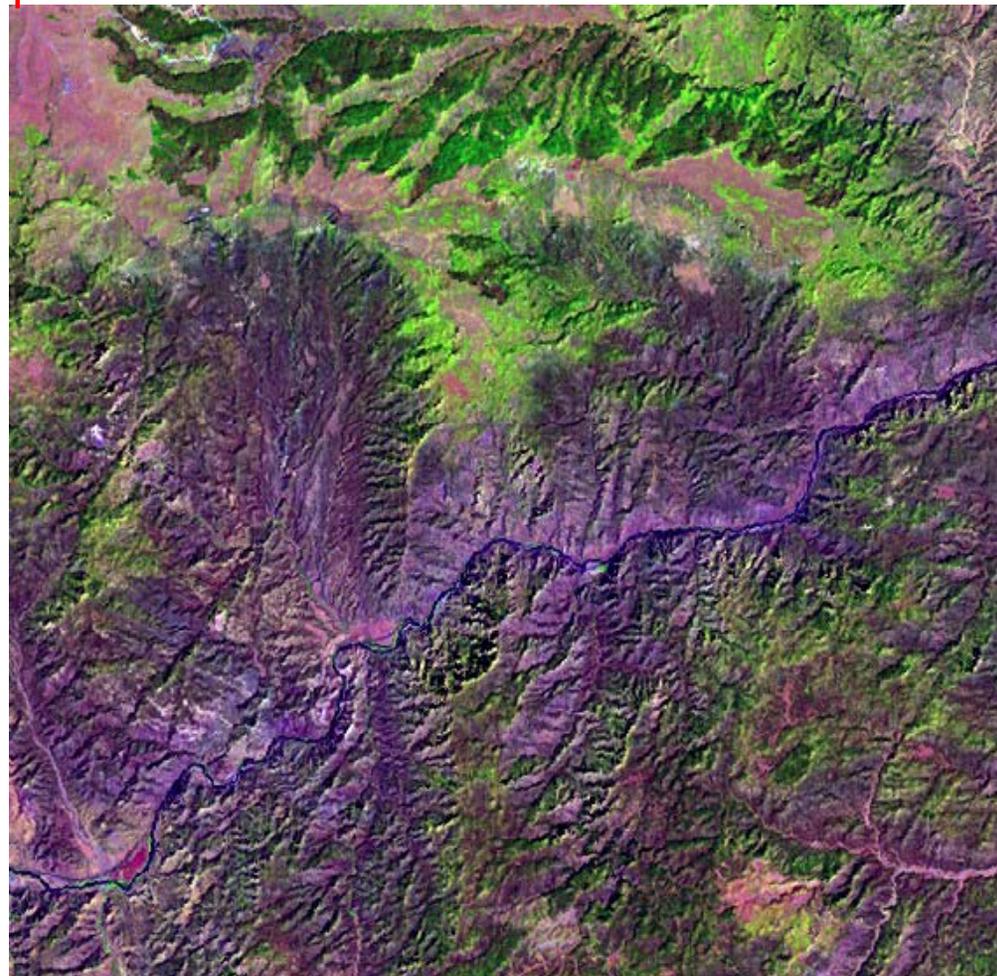
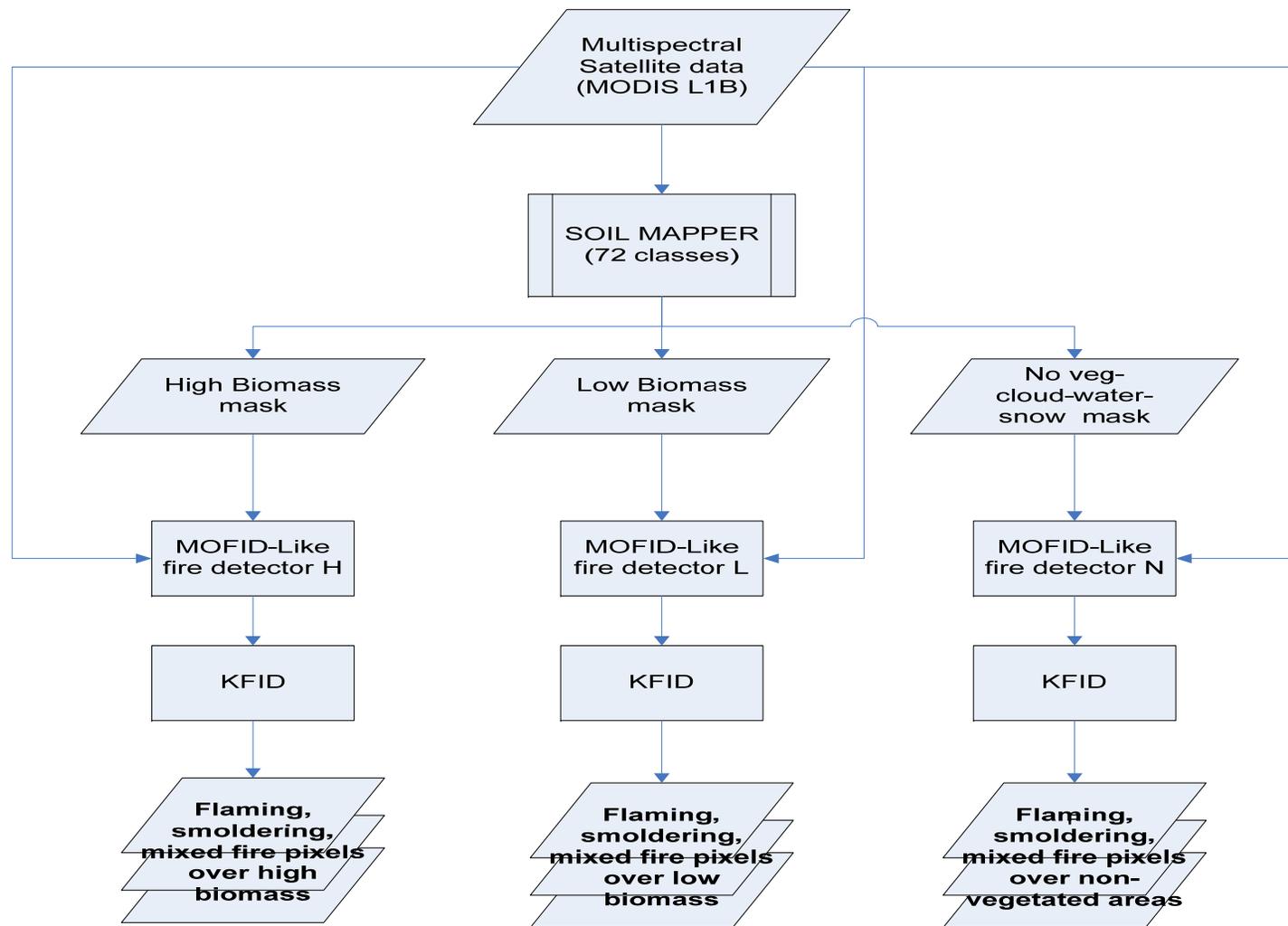


Fig. B. Stratified topographic correction of Fig. A, based on a 16-class preliminary spectral map and the SRTM DEM.

## Application domain 3.d.

Stratified image classification. Example: SOIL MAPPER-driven Fire Detection (SOMAFID) algorithm for MODIS, MSG, and AATSR.



Kaufman's rule-based detection of: a) flaming fire, b) smoldering fire (Kaufman et al., Potential global fire monitoring from EOS-MODIS, Journal of Geophysical Research, 103, 32215 – 32238, 1998).

## Application domain 3.d.

Stratified image classification. Example: **fire detection** in MODIS imagery combined with smoke **plume detection**.



Fig. A. MODIS image acquired on August 23, 2007, at 9.35 (CEST), covering Greece (R: band 6, G: band 2, B: band 3), spatial resolution: 1 km.

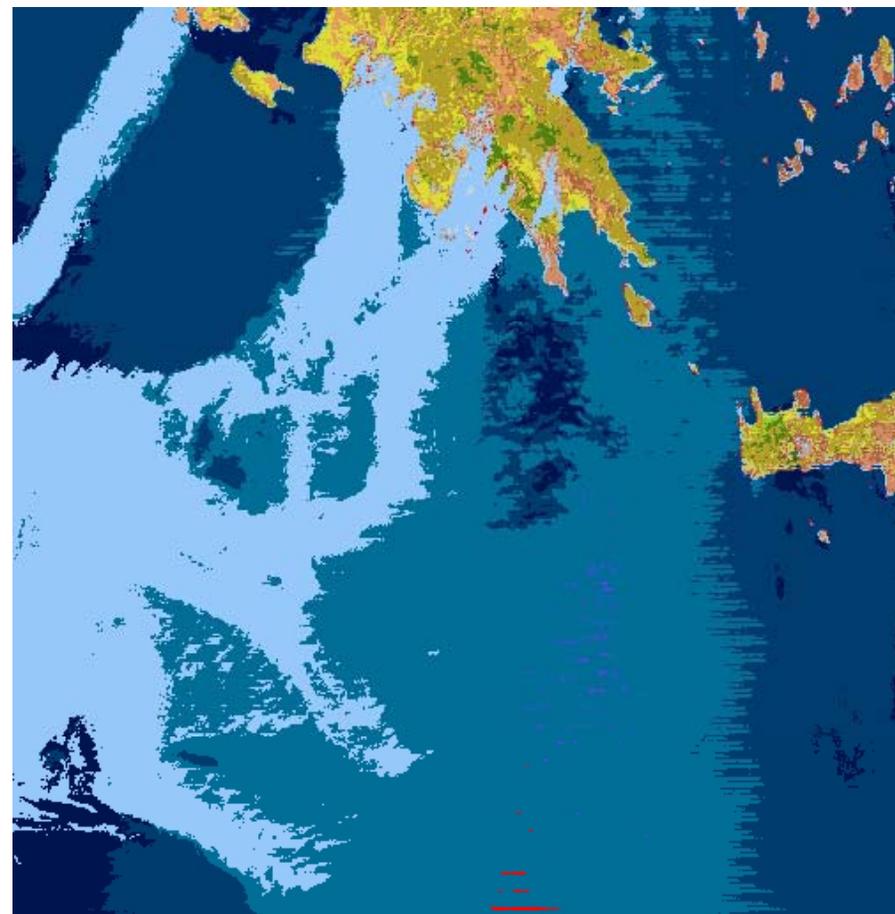


Fig. B. Output map generated from Fig. A, consisting of 82 spectral categories, depicted in pseudo-colors.

## Application domain 3.d.

Stratified image classification. Example: **fire detection** in MODIS imagery combined with smoke **plume detection**.

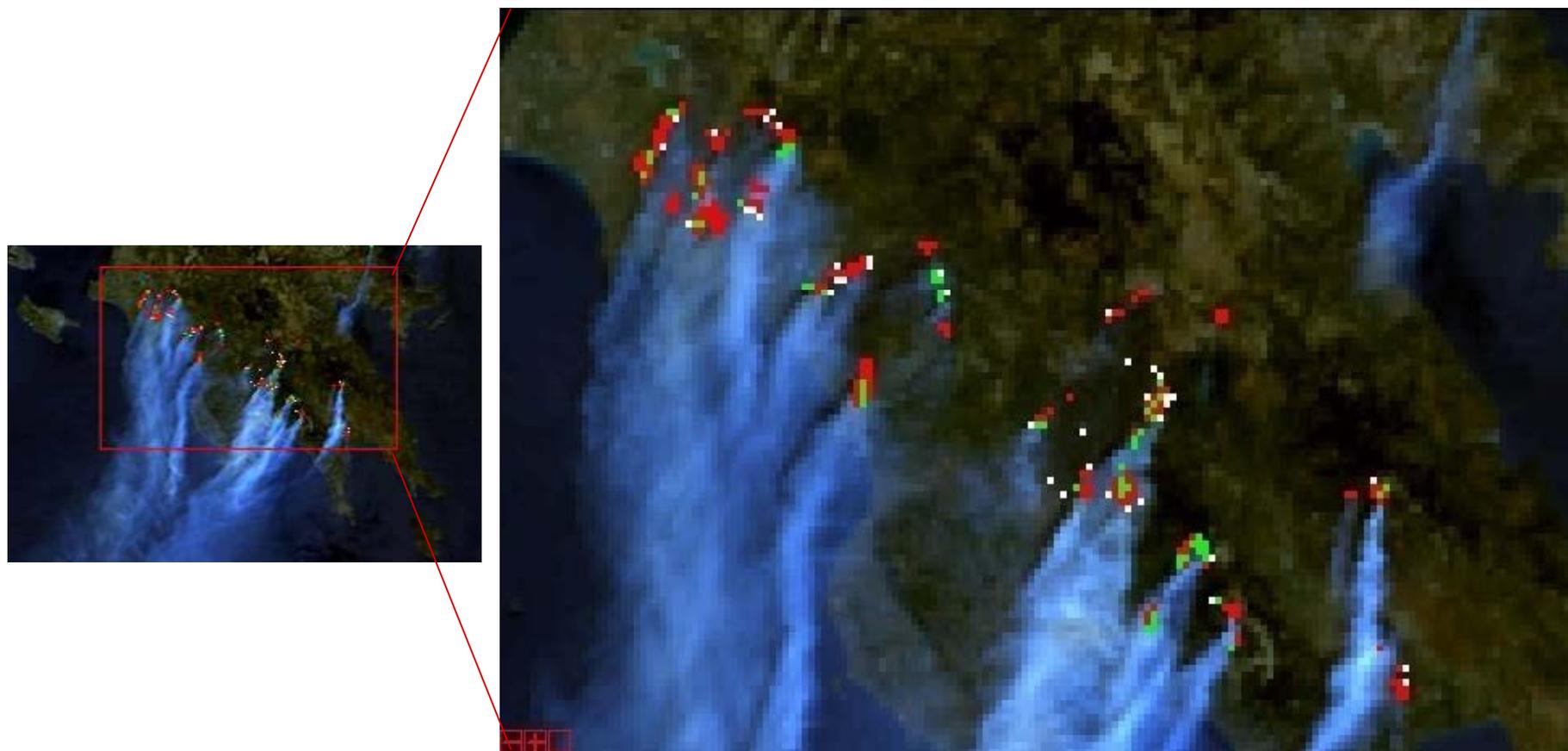


Fig. A. MODIS image acquired on August 23, 2007, at 9.35 (CEST), covering Greece (R: band 6, G: band 2, B: band 3), spatial resolution: 1 km. Legend – Red: fire pixel detected in both MODIS Fire Detection (MOFID) and SOIL MAPPER® -based Fire Detection (SOMAFID). White: fire pixel detected by SOMAFID, exclusively. Green: fire pixel detected by MOFID, exclusively.

## Application domain 4.

Bi-temporal semantic-based land cover change detection. Landsat-5 TM imagery. Example a: Brazil.

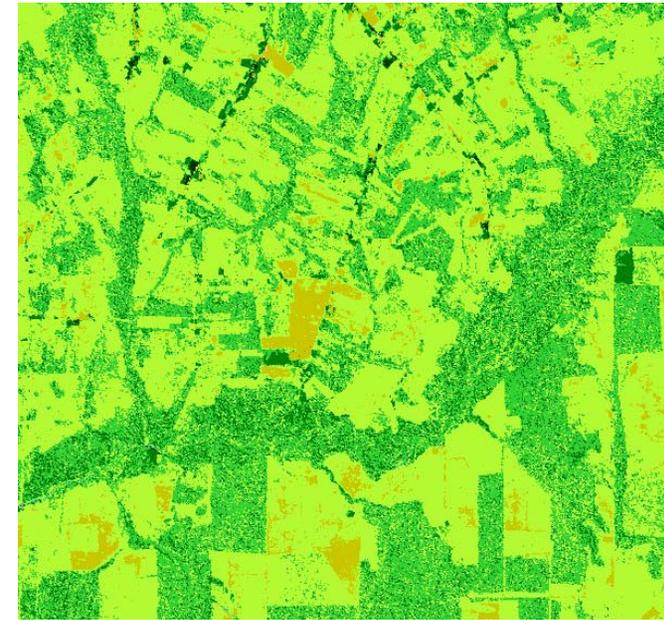


Fig. A. Zoom of a preliminary classification map depicted in pseudo colors, generated from a Landsat-5 TM imagery (acquired on 1985-08-10, covering an area of Brazil (path: 231, row: 068), spatial resolution: 30 m).

Fig. B. Zoom of a preliminary classification map depicted in pseudo colors, generated from a Landsat-5 TM imagery acquired on 2006-07-16, covering an area of Brazil (path: 231, row: 068), spatial resolution: 30 m.

Fig. C. Zoom of a Bi-Temporal change detection map generated from the preliminary classification map pair shown in Fig. A and Fig. B.

## Application domains 1, 2 and 4.

Baseline map generation / Burned area detection (in single date imagery!!!).

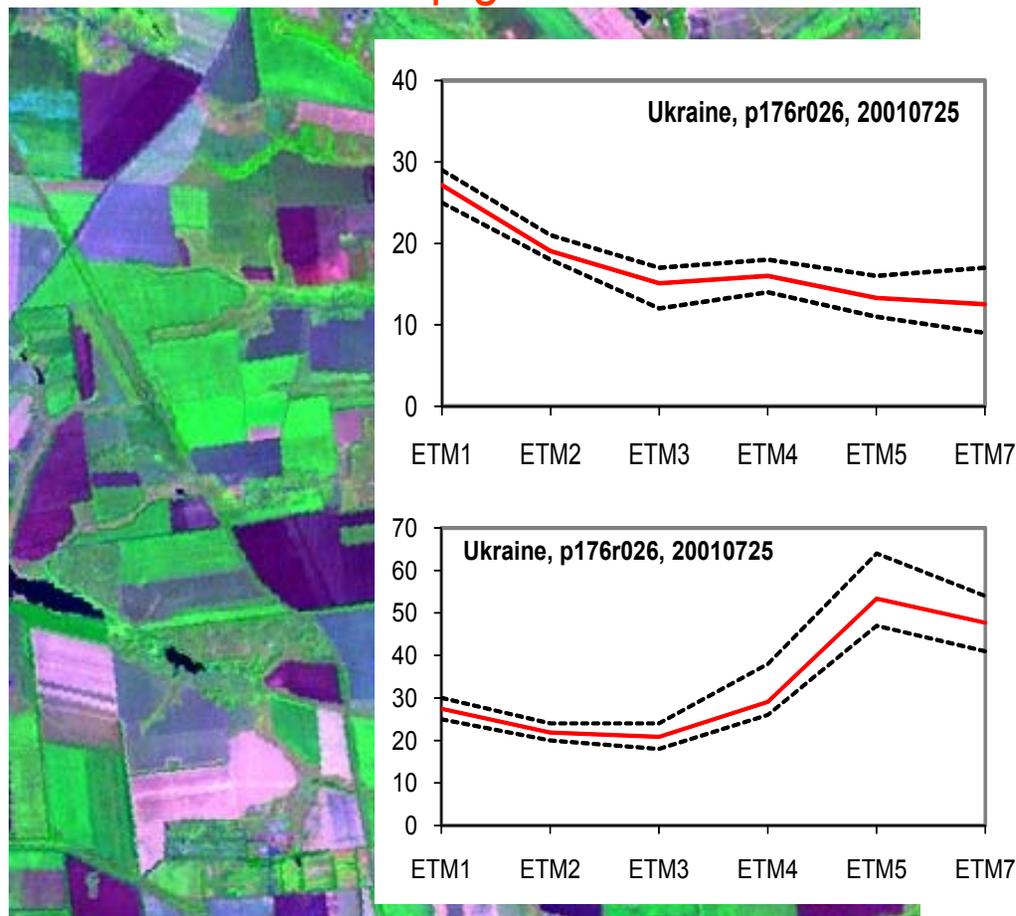


Fig. A. Zoomed area extracted from a Landsat 7 ETM+ image depicted in false colors (R: band TM5, G: band TM4, B: band TM1). Path: 176, Row: 026, acquisition date: 2001-07-25, Ukraine.



Fig. B. Output map generated from Fig. A, consisting of 88 spectral categories depicted in pseudo colors. Violet: old and recently burned areas. Green tones: vegetation and rangeland, Brown and grey color shades: barren land and built-up areas, Blue tones: water types, White tones: clouds.

# Application domain 4.

Semantic-based Discrete Greenness change detection. Landsat-5 TM imagery. Example c: Greece.

Landsat 5 TM, 20-10-92



Landsat 5 TM, 29-10-95

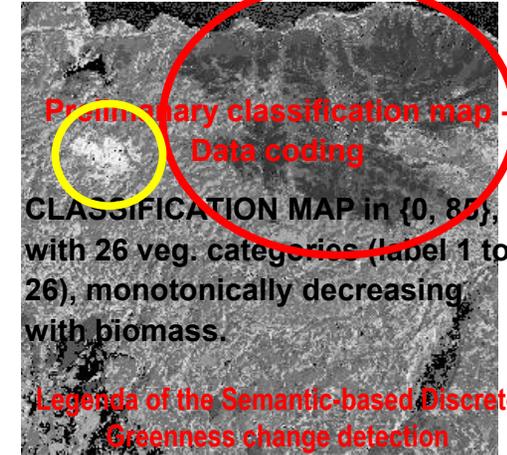


Landsat 5 TM, 21-10-98



Preliminary spectral maps, 85 spectral classes, depicted in pseudo colors.

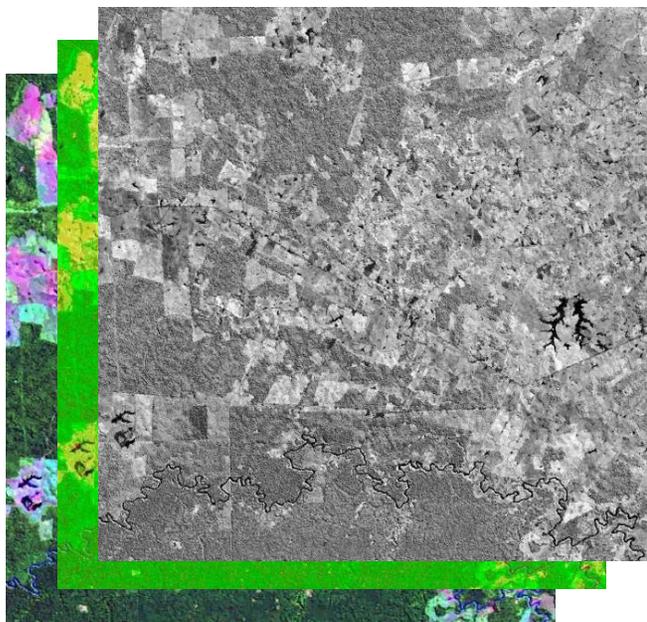
Spectral map difference, 95-92.



Spectral map difference, 98-92.

## Application domain 4.

Semantic-based Continuous Greenness change detection. Landsat-7 ETM+ imagery. Example d: Brazil.

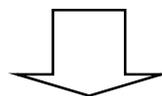


Input image 1: Landsat 5 TM image of Brazil (path: 002, row: 067, acquisition date: 1993).

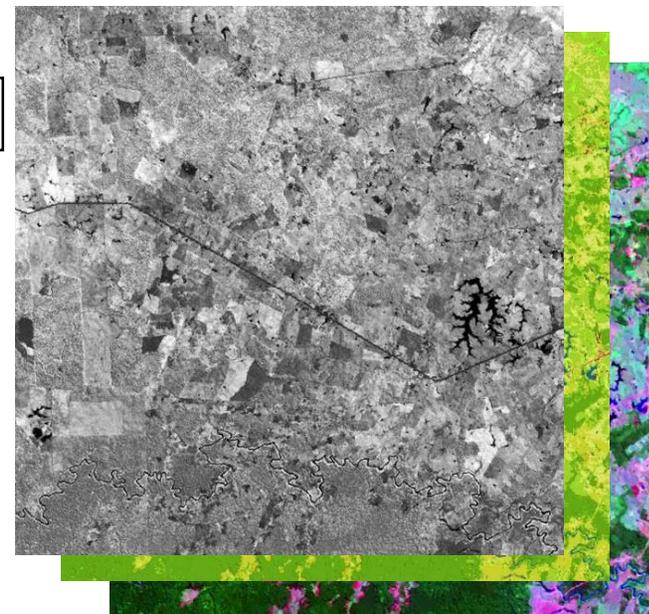
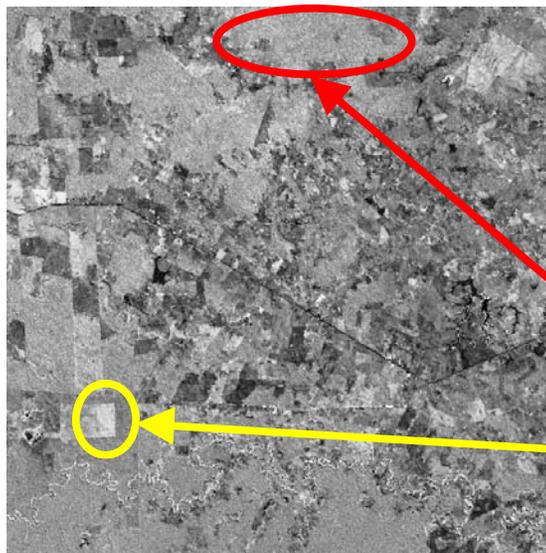
**Note:**

In case, a preliminary classification map pair difference ( $CLMap_{t1} - CLMap_{t2}$ ),  $t1 < t2$ , is possible because the classification map indexes decrease monotonically with greenness estimates.

1. Spectral classification map in  $\{0, 85\}$ , with 26 veg. categories (label 1 to 26).
2. Greenness estimate  $\geq 0$ .



Bi-temporal Greenness Estimate Image Difference masked by  $VegMask_{t1}$  and  $VegMask_{t2}$ ,  $t2 > t1$ , range  $(-\infty, +\infty)$ .



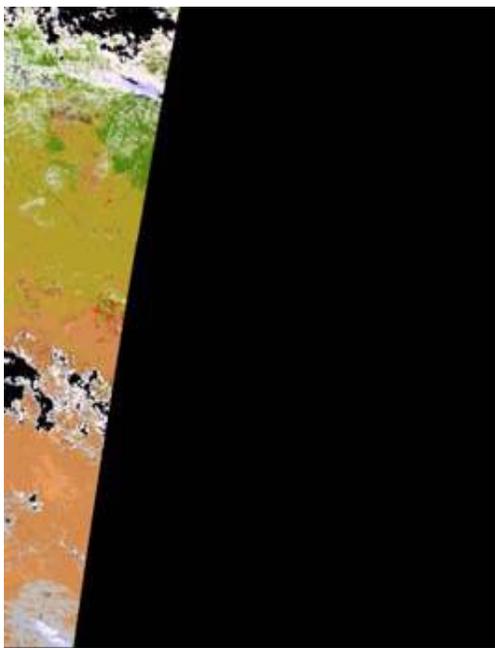
Input image 2: Landsat 7 ETM+ image of Brazil (path: 002, row: 067, acquisition date: 1999).

**Greenness Estimate Image Difference - Legend:**

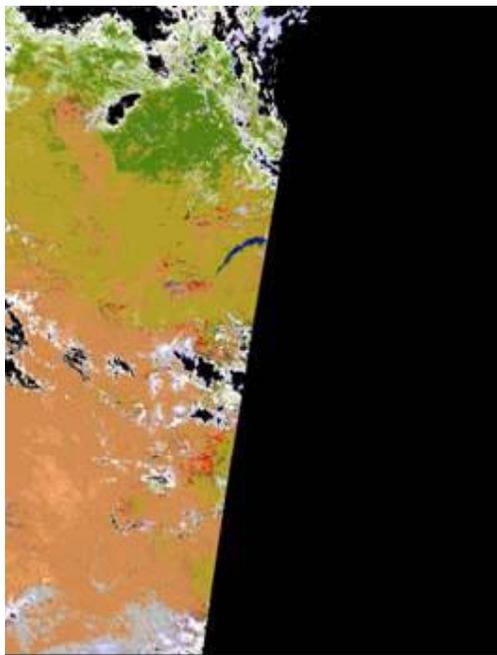
- $< 0$ : Greenness loss from time  $t1$  to  $t2 > t1$ .
- $> 0$ : Greenness gain from time  $t1$  to  $t2 > t1$ .

## Application domain 4.

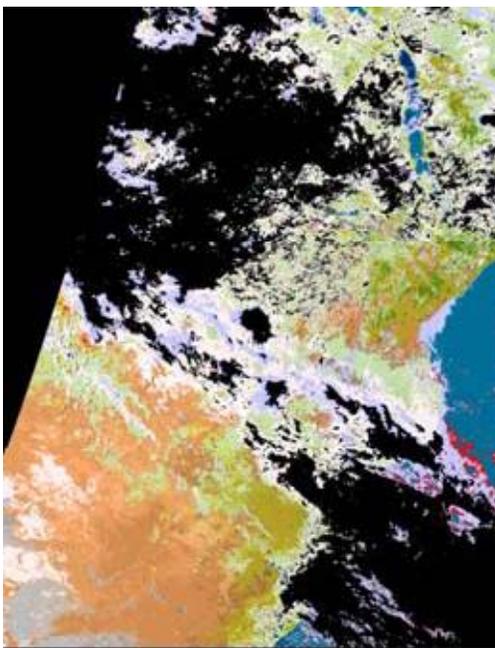
Semantic-based composition of a temporal sequence of classification maps. SPOT-5 VMI imagery. Example e: Zimbabwe.



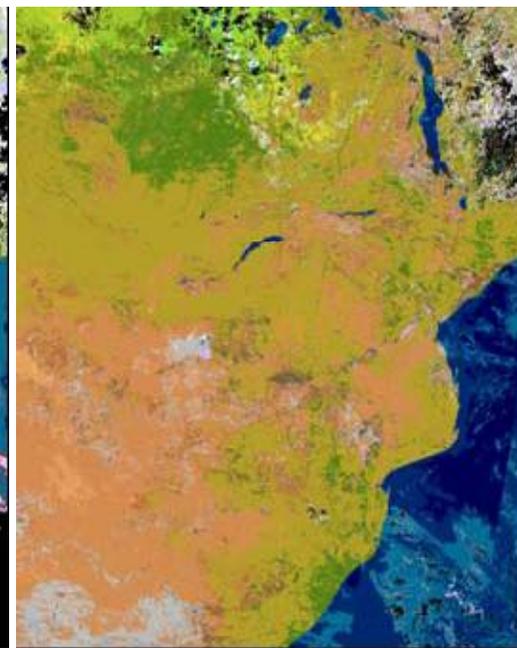
49 spectral category-map, depicted in pseudo colors, generated from a SPOT-5 VMI image of Zimbabwe acquired on 01-12-2006, spatial resolution: 1.1 km.



49 spectral category-map, depicted in pseudo colors, generated from a SPOT-5 VMI image of Zimbabwe acquired on 02-12-2006, spatial resolution: 1.1 km.



49 spectral category-map, depicted in pseudo colors, generated from a SPOT-5 VMI image of Zimbabwe acquired on 31-12-2006, spatial resolution: 1.1 km.



Semantic-based composition of 49 spectral category-maps, depicted in pseudo colors, generated from a sequence of SPOT-5 VMI images of Zimbabwe acquired on Dec. 2006, spatial resolution: 1.1 km.

# Application domain 4. Automatic landscape connectivity.

CONEFOR SENSINODE 2.5 software. Available for download from: [www.conefor.udl.es](http://www.conefor.udl.es)  
 ssaura@eagrof.udl.es, [www.udl.es/usuarios/saura](http://www.udl.es/usuarios/saura)

The different ways in which a patch can contribute to habitat availability and connectivity in the landscape

$$dPC_k = dPCintra_k + dPCflux_k + dPCconnector_k$$

The diagram shows three types of green patches in a landscape:

- Isolated Patch:** A single patch with no connections. Its contribution is defined as:
 
$$dPCintra > 0$$

$$dPCflux = 0$$

$$dPCconnector = 0$$
- Cluster Patch:** A patch within a group of connected patches. Its contribution is defined as:
 
$$dPCintra > 0$$

$$dPCflux > 0$$

$$dPCconnector = 0$$
- Connector Patch:** A patch that links two separate clusters of patches. Its contribution is defined as:
 
$$dPCintra > 0$$

$$dPCflux > 0$$

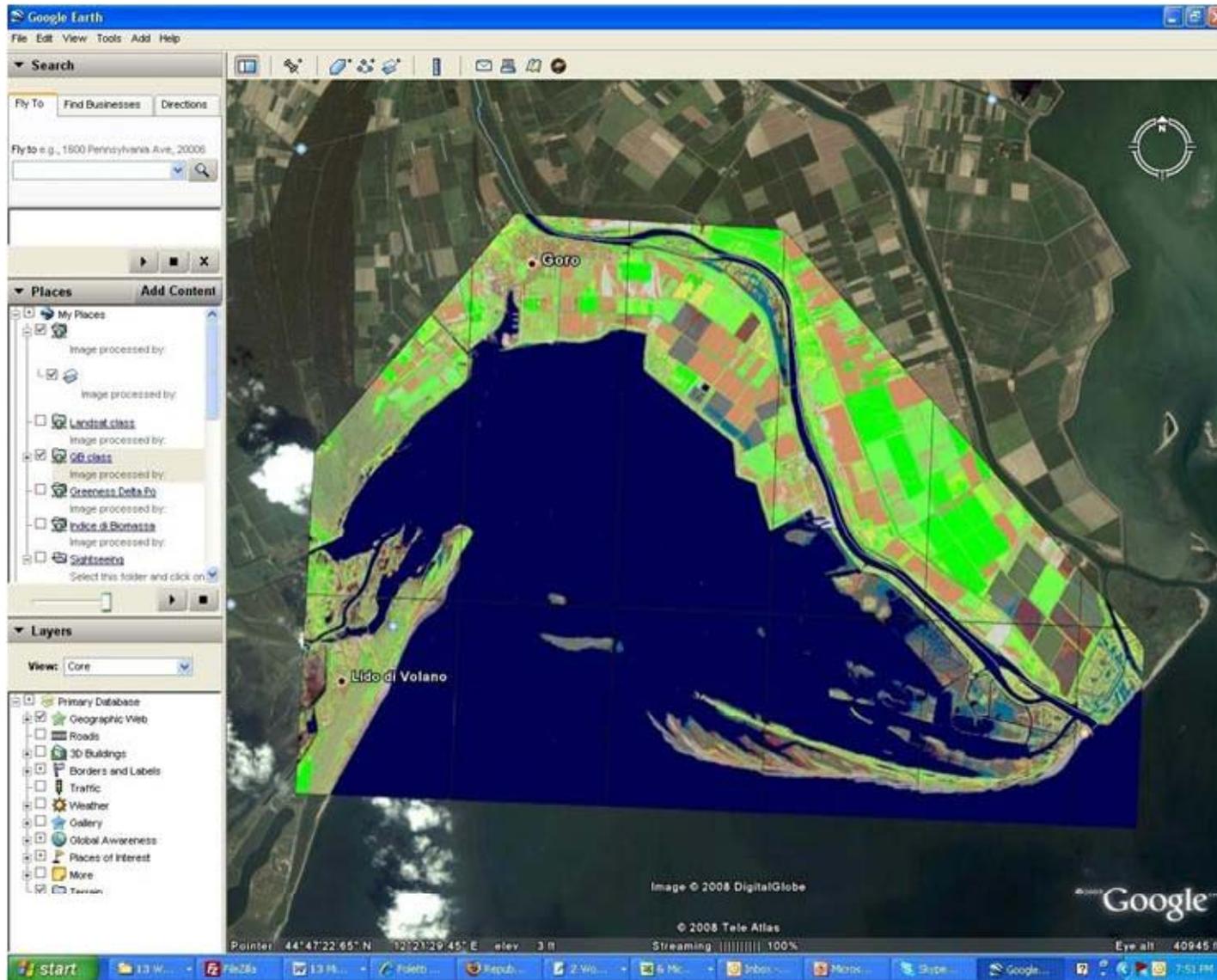
$$dPCconnector > 0$$



# Application domain 5. Virtual globe-based map visualization/generation on demand.

Preliminary spectral map, depicted in pseudo colors, generated from a QuickBird-2 image of the Goro area in the Po river delta, Italy (acquisition date: 2003-05-28, 12:45; spatial resolution: 2.44m), calibrated into TOA reflectance.

The map is transformed into the kml data format and, finally, it is loaded as a thematic layer in a commercial 3-D earth viewer (Google Earth).





es



Map data © 2007 DMapas/El Mercurio  
© 2007 Europa Technologies  
© 2007 Tele-Atlas  
Image NASA

© 2007 Google™

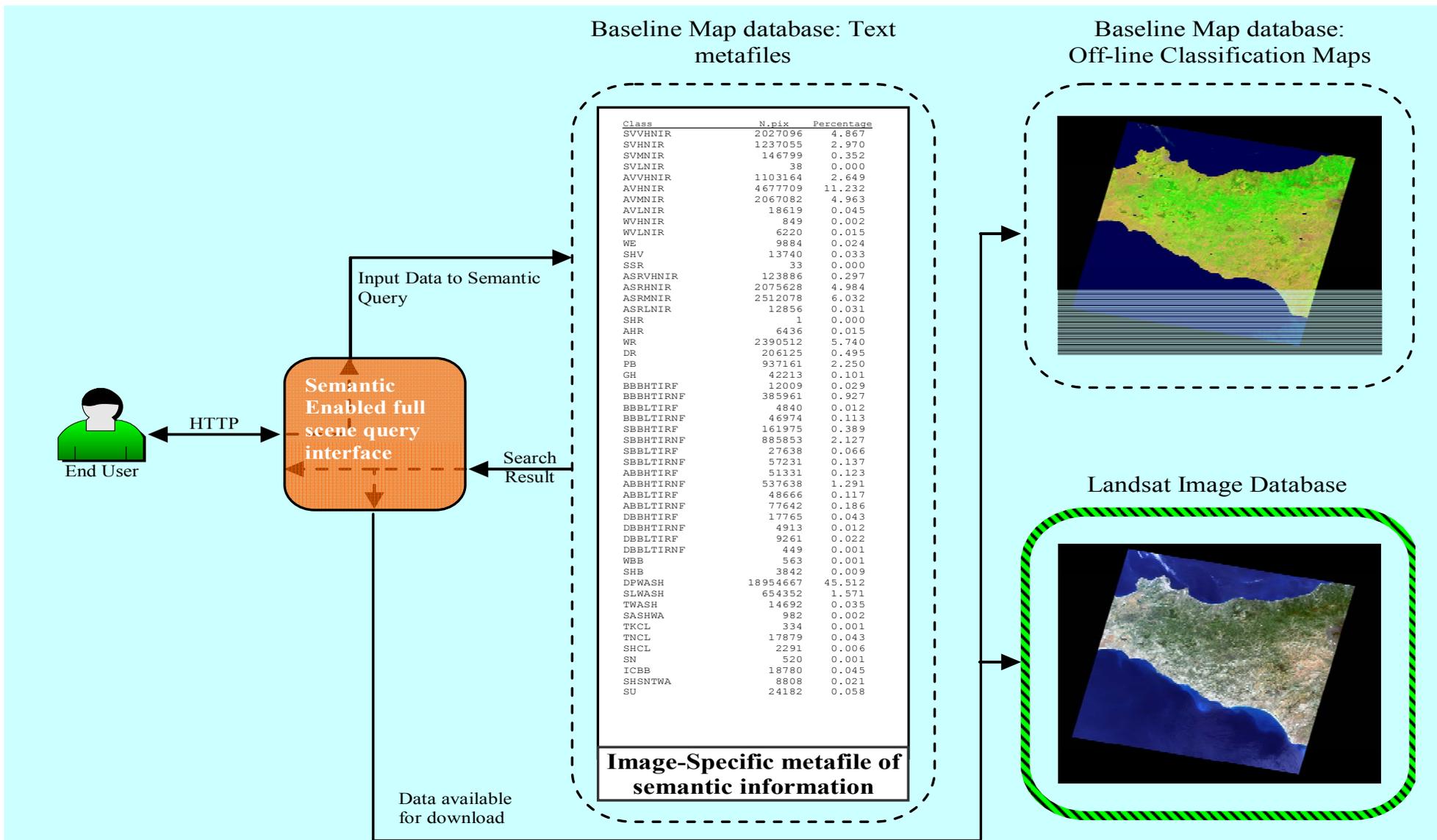
Puntatore 44°39'52.72" N 12°29'05.04" E

Streaming ||||| 100%

Alt 11733.66 km

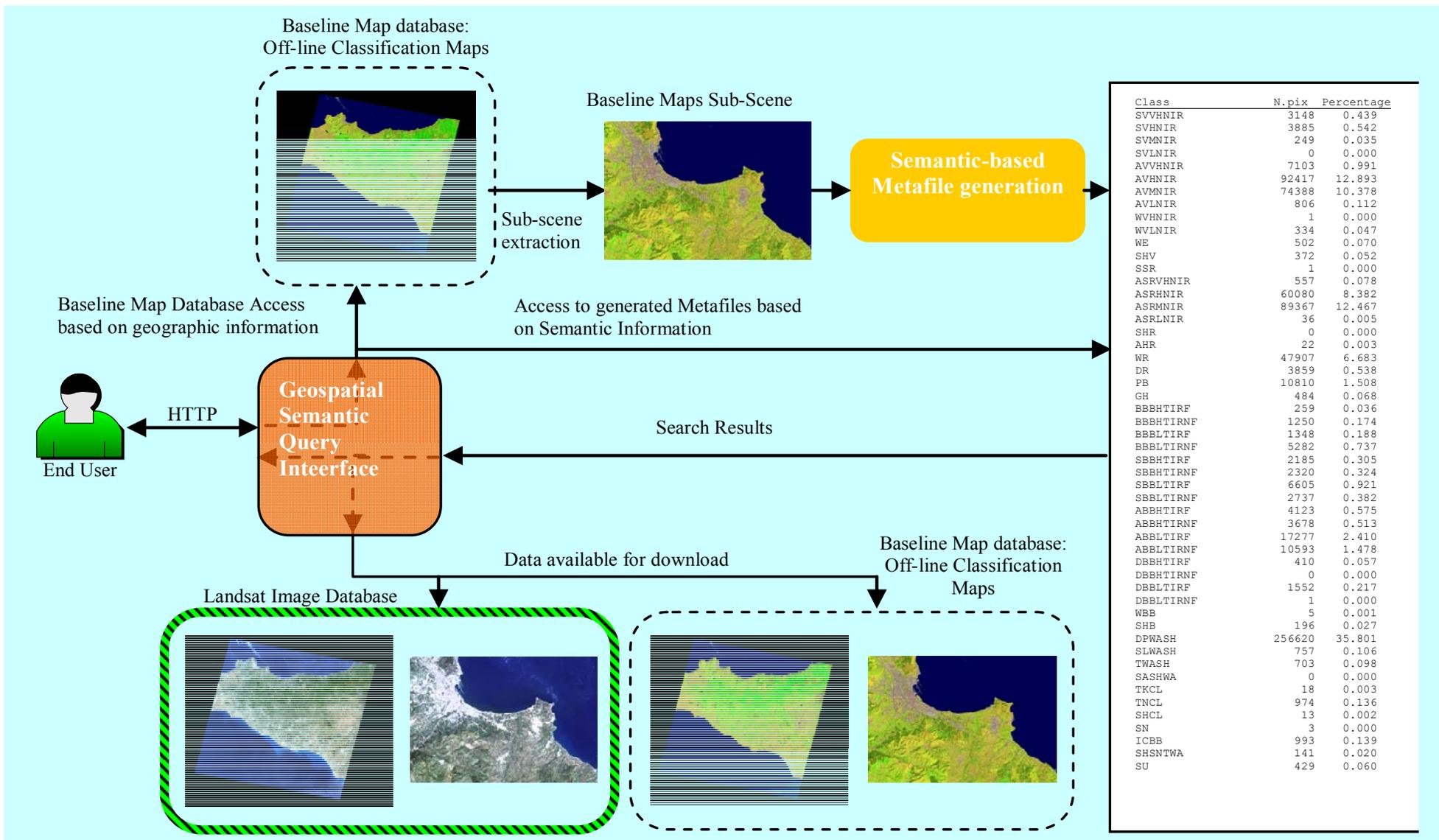
# Application domain 5.

Example b: statistical semantic queries into an image database.



# Application domain 5.

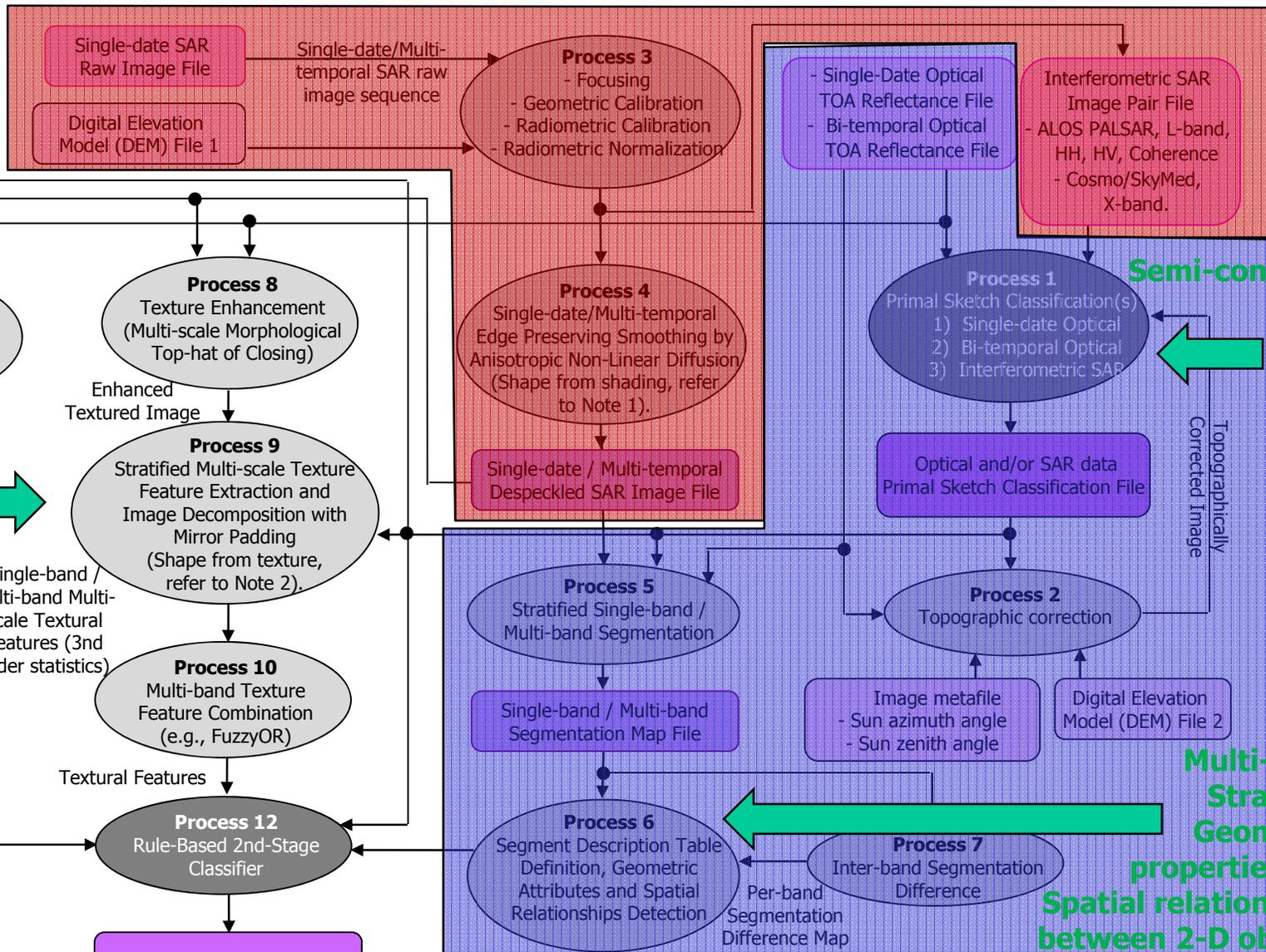
Example b: statistical semantic queries into an image database.



# Optical-SAR data fusion at the semantic level

Note 1. Shape-from-shading = finding boundaries between regions of uniform but different intensity / spectral values.

Multi-scale Stratified Morphological profile



Semi-concepts

Multi-scale Stratified Texture analysis

Multi-scale Stratified Geometric properties and Spatial relationships between 2-D objects

Note 2. Shape-from-texture = finding boundaries between regions of uniform but different textures.

**Land cover classes:** 1) Bare soil, 2) road, 3) building, 4) impervious surface, 5) grassland, 6) forest, 7) agricultural field: i) orchard, ii) vineyard, iii) tilled field, 8) shrubland, 9) water, 10) cloud, 11) snow, 12) shadow.

# Automatic optical image SIAM™ classification: Landsat-5 TM, 1986.

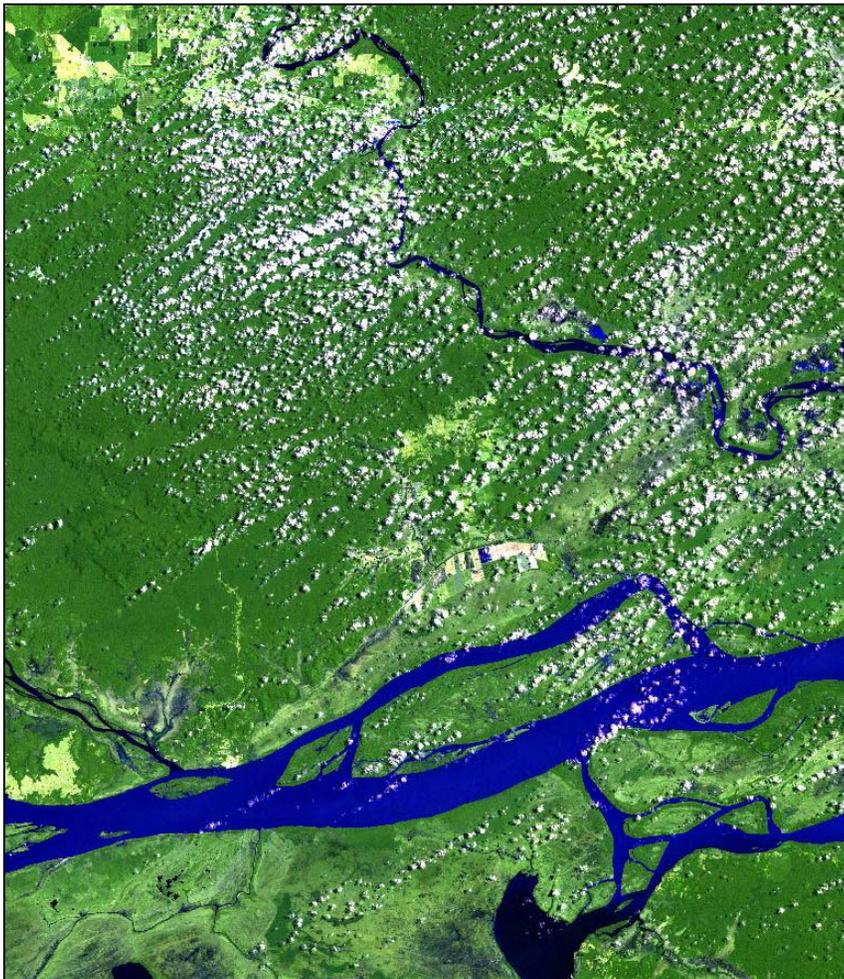


Fig. A. Landsat-5 TM image of Brazilian Amazon (acquisition date: october 1986), depicted in false color (R: band TM5, G: band TM4, B: band TM1) .

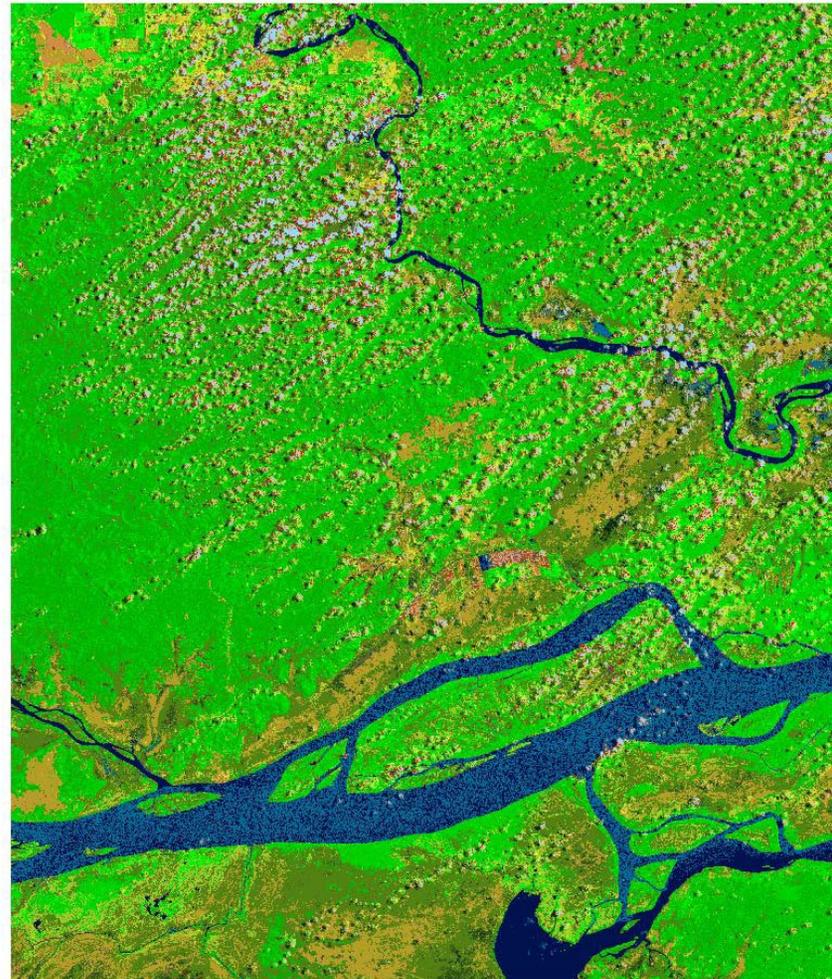


Fig. B. Spectral map generated from Fig. A featuring 49 spectral types (strata, categories), depicted in pseudo colors.



# Automatic SAR image rule-based classification: ALOS PALSAR HH/HV, 2007.

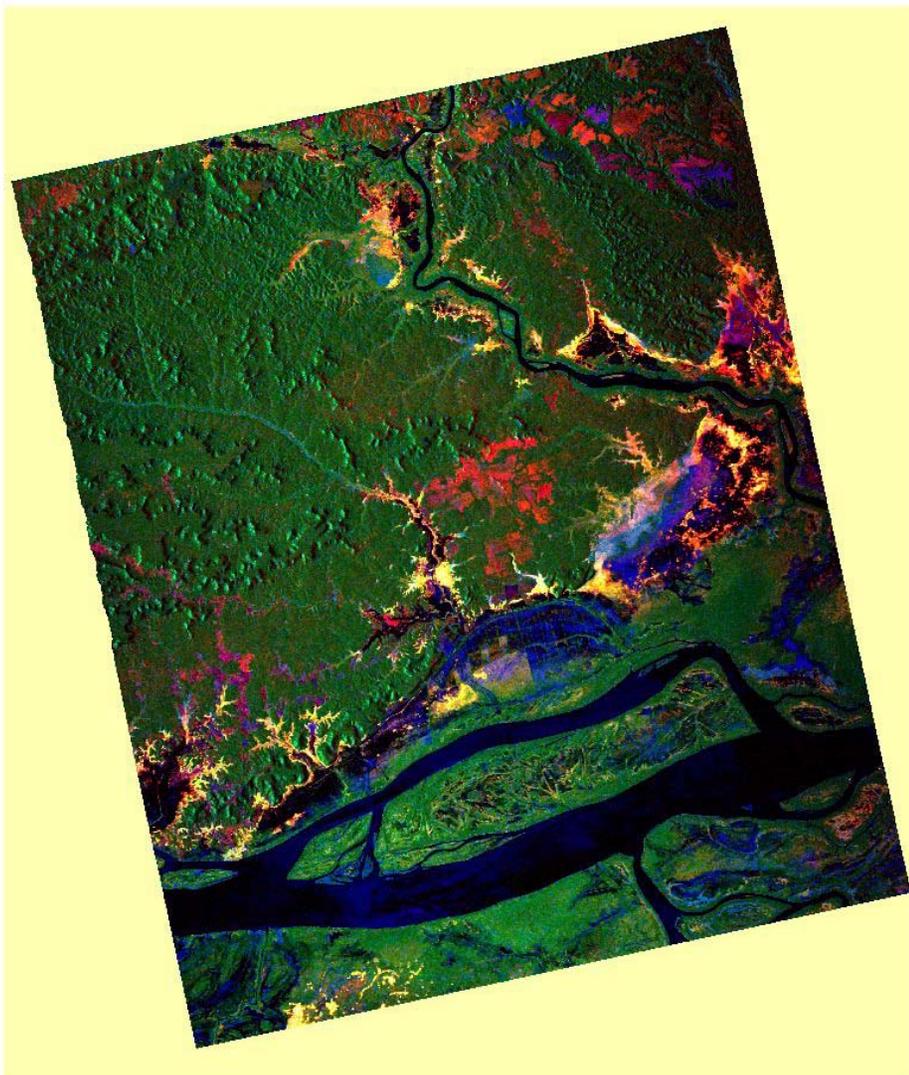


Fig. A. Interferometric ALOS PALSAR HH/HV Dual Polarization (acquisition date: June-Aug 2007) image of Brazilian Amazon (R: coherence, G: average intensity, B: intensity difference).

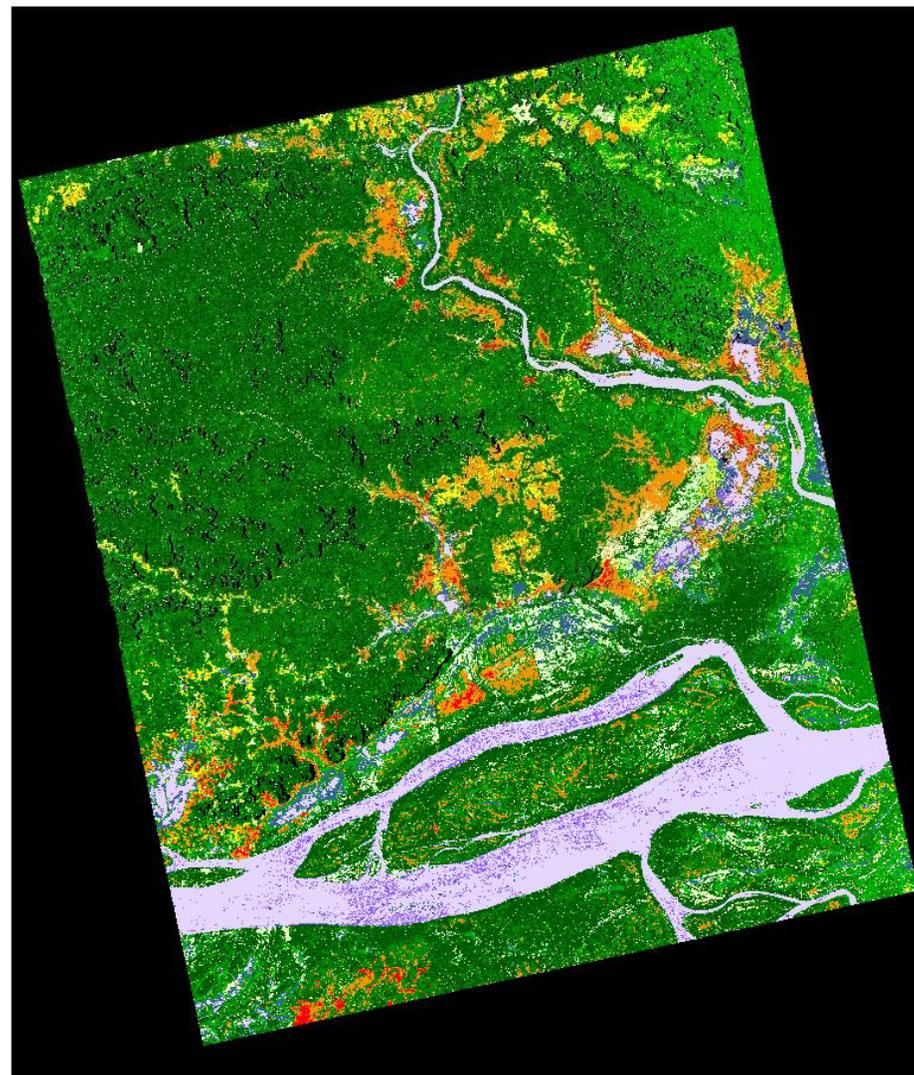


Fig. B. SAR data preliminary classification map of the image shown in Fig. A-

# Bi-temporal SAR-optical data change detection: 1986-2007.



Legend

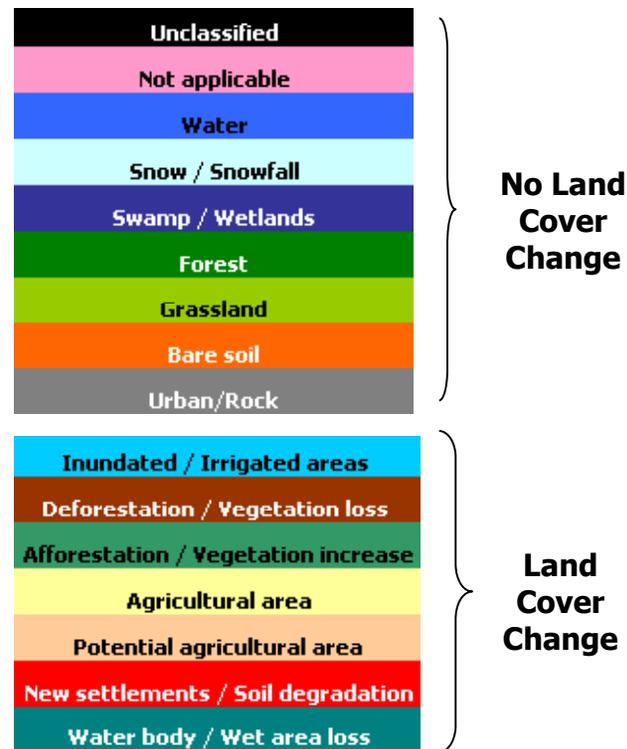


Fig. A. Semantic change detection in a SAR-optical data preliminary map pair.